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SPECIFIATION

DEVICE AND METHOD OF CONTROLLING EXHAUST GAS SENSOR
TEMPERATURE, AND RECORDING MEDIUM FOR EXHAUST GAS SENSOR
TEMPERATURE CONTROL PROGRAM

Technical field:

The present invention relates to an apparatus
for and a method of controlling the temperature of an ex-
haust gas sensor disposed in the exhaust passage of an in-
ternal combustion engine, and a recording medium storing a
program for controlling the temperature of such an exhaust
gas sensor.

Background art:

Exhaust gas sensors are often disposed in the
exhaust passages of internal combustion engines for detect-
ing a physical quantity as to an exhaust gas component
state, such as an exhaust gas component concentration, for
the purpose of controlling the operation of the internal
combustion engine or monitoring the status of an exhaust
gas purifying system. Specifically, an exhaust gas sensor
is disposed at a certain location in the exhaust gas pas-
sage and has an element sensitive to an exhaust gas compo-
nent state to be detected, the element being positioned for
contact with an exhaust gas flowing through the exhaust
passage. For example, an air-fuel ratio sensor such as an
O_2 sensor or the like is disposed as an exhaust gas sensor

upstream or downstream of an exhaust gas purifying catalyst disposed in the exhaust passage for the purpose of controlling the air-fuel ratio of the internal combustion engine in order to keep well the purifying ability of the catalyst.

Some air-fuel ratio sensors have a built-in heater for heating the active element thereof for increasing the temperature of the element and activating the element to enable the element to perform its essential functions and also removing foreign matter deposited on the element. For example, an air-fuel ratio sensor such as an O_2 sensor or the like usually has an electric heater for heating the active element thereof. After the internal combustion engine has started to operate, the electric heater is energized to increase the temperature of the active element of the O_2 sensor to activate the active element and keep the active element active.

As shown in FIG. 3 of the accompanying drawings, the O_2 sensor produces an output voltage Vout which changes with a large gradient with respect to a change in the air-fuel ratio of an exhaust gas, i.e., which is highly sensitive to a change in the air-fuel ratio, only in a small range Δ (near a stoichiometric air-fuel ratio) of values of the air-fuel ratio that is represented by an oxygen concentration in the exhaust gas to which the active element is sensitive. A change in the output voltage Vout of the O_2

sensor, i.e., a gradient of the output voltage Vout with respect to the air-fuel ratio, is smaller in air-fuel ratio ranges that are richer and leaner than the highly sensitive range Δ. The output characteristics of the O_2 sensor, i.e., the gradient of the highly sensitive range Δ, etc., vary depending on the temperature of the active element. When the air-fuel ratio is to be controlled using the output voltage from the O_2 sensor, therefore, it is desirable to keep the output characteristics of the O_2 sensor in a desired range as much as possible and hence to keep the temperature of the active element of the O_2 sensor in a desired temperature range as stably as possible for better air-fuel ratio control.

Not only O_2 sensors but also many exhaust gas sensors have their output characteristics affected by the temperature of the active element. If the internal combustion engine is to be controlled using the output signal from the O_2 sensor, then it is preferable to keep the temperature of the active element of the exhaust gas sensor in a desired temperature range as stably as possible for better engine control. When the active element of the exhaust gas sensor is heated to clean the active element, it is also preferable to keep the temperature of the active element of the exhaust gas sensor in a desired temperature range for a better cleaning effect.

As disclosed in Japanese laid-open patent publi-
cation No. 2000-304721 by the applicant of the present ap-
plication, it is known to estimate the temperature of the
active element of an exhaust gas sensor (an air-fuel ratio
sensor in the publication) and control the energization of
a heater (an electric heater) based on the estimated tem-
perature for thereby keep the temperature of the active
element in a desired temperature range to obtain appropri-
ate output characteristics from the exhaust gas sensor.
According to the disclosed arrangement, the resistance of
the heater is recognized from detected values of a current
flowing through the heater and a voltage applied across the
heater, and the temperature of the active element is esti-
mated based on the detected resistance of the heater.

According to the disclosure of the above publi-
cation, however, since the temperature of the active ele-
ment of the exhaust gas sensor is merely estimated based on
the resistance of the heater, the reception of thermal en-
ergy, such as heat transfer between the heater and the ac-
tive element, is not sufficiently taken into account.
Therefore, it is difficult to accurately estimate the tem-
perature of the active element of the exhaust gas sensor.
According to the disclosure of the above publication, fur-
thermore, a duty cycle which determines the electric power
to be supplied to the heater is uniquely determined by a
table from an estimated value of the temperature of the ac-

tive element of the exhaust gas sensor. As a result, it is difficult to control the temperature of the active element of the exhaust gas sensor stably at a desired temperature.

The present invention has been made in view of the above background. It is an object of the present invention to provide an apparatus for and a method of accurately estimating the temperature of the active element of an exhaust gas sensor or a heater, and controlling the temperature of the active element of the exhaust gas sensor stably at a desired temperature, using the estimated value of the temperature. Another object of the present invention is to provide a recording medium storing a temperature control program for accurately estimating the temperature of the active element of an exhaust gas sensor or a heater, and controlling the temperature of the active element of the exhaust gas sensor stably at a desired temperature, using the estimated value of the temperature.

Disclosure of the invention:

An apparatus for controlling the temperature of an exhaust gas sensor according to the present invention is a temperature control apparatus for an exhaust gas sensor disposed in an exhaust passage of an internal combustion engine and having an active element for contacting an exhaust gas flowing through the exhaust passage and a heater for heating the active element. To achieve the above ob-

ject, a temperature control apparatus according to a first aspect of the present invention is characterized by temperature estimating means for sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of a temperature change of the active element due to heat transfer between at least the active element and an exhaust gas held in contact with the active element, and heater control means for controlling the heater to equalize the temperature of the active element with a predetermined target temperature, using an estimated value of the temperature of the active element from the temperature estimating means.

A method of controlling the temperature of an exhaust gas sensor according to the present invention is a temperature control method for an exhaust gas sensor disposed in an exhaust passage of an internal combustion engine and having an active element for contacting an exhaust gas flowing through the exhaust passage and a heater for heating the active element. To achieve the above object, a temperature control method according to the first aspect of the present invention is characterized by, while sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of a temperature change of the active element due to heat transfer between at least the active element and an exhaust gas held in contact with the active

element, controlling the heater to equalize the temperature
of the active element with a predetermined target tempera-
ture, using an estimated value of the temperature of the
active element.

A recording medium storing a temperature control
program for an exhaust gas sensor according to the present
invention is a recording medium readable by a computer and
storing a temperature control program for enabling the com-
puter to perform a process of controlling the temperature
of an exhaust gas sensor disposed in an exhaust passage of
an internal combustion engine and having an active element
for contacting an exhaust gas flowing through the exhaust
passage and a heater for heating the active element. To
achieve the above object, a recording medium according to
the first aspect of the present invention is characterized
in that the temperature control program comprises a tem-
perature estimating program for enabling the computer to
perform a process of sequentially estimating the tempera-
ture of the active element based on a predetermined element
temperature model which is representative of a temperature
change of the active element due to heat transfer between
at least the active element and an exhaust gas held in con-
tact with the active element, and a heater control program
for enabling the computer to perform a process of control-
ling the heater to equalize the temperature of the active

element with a predetermined target temperature, using an estimated value of the temperature of the active element.

The term "heat transfer" used in the present invention covers heat transfer through direct contact and heat transfer through air. This definition applies to other inventions of the present application.

According to the first aspect of the present invention, the element temperature model is representative of a temperature change of the active element due to heat transfer between at least the active element and an exhaust gas held in contact with the active element. Therefore, when the temperature of the active element is estimated based on the element temperature model, the temperature of the active element can be estimated taking into account a temperature change of the active element due to heat transfer between the active element and the exhaust gas. As a result, the accuracy of the estimated value of the temperature of the active element is increased. By controlling the heater to equalize the temperature of the active element with a predetermined target temperature (desired temperature), using the estimated value of the temperature of the active element, it is possible to control the temperature of the active element stably at the target temperature.

A temperature control apparatus for an exhaust gas sensor according to a second aspect of the present in-

vention is characterized by temperature estimating means
for sequentially estimating the temperature of the active
element based on a predetermined element temperature model
which is representative of a temperature change of the ac-
tive element due to heat transfer between at least the ac-
tive element and the heater, and heater control means for
controlling the heater to equalize the temperature of the
active element with a predetermined target temperature, us-
ing an estimated value of the temperature of the active
element from the temperature estimating means.

Similarly, a temperature control method for an
exhaust gas sensor according to the second aspect of the
present invention is characterized by, while sequentially
estimating the temperature of the active element based on a
predetermined element temperature model which is represen-
tative of a temperature change of the active element due to
heat transfer between at least the active element and the
heater, controlling the heater to equalize the temperature
of the active element with a predetermined target tempera-
ture, using an estimated value of the temperature of the
active element.

A recording medium storing a temperature control
program for an exhaust gas sensor according to the second
aspect of the present invention is characterized in that
the temperature control program comprises a temperature es-
timating program for enabling the computer to perform a

process of sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of a temperature change of the active element due to heat transfer between at least the active element and the heater, and a heater control program for enabling the computer to perform a process of controlling the heater to equalize the temperature of the active element with a predetermined target temperature, using an estimated value of the temperature of the active element.

According to the second aspect of the present invention, the element temperature model is representative of a temperature change of the active element due to heat transfer between at least the active element and the heater. Therefore, when the temperature of the active element is estimated based on the element temperature model, the temperature of the active element can be estimated taking into account a temperature change of the active element due to heat transfer between the active element and the heater. As a result, the accuracy of the estimated value of the temperature of the active element is increased. By controlling the heater to equalize the temperature of the active element with a predetermined target temperature (desired temperature), using the estimated value of the temperature of the active element, it is possible to control

the temperature of the active element stably at the target temperature.

Both the first and second aspects of the present invention should preferably be combined with respect to either one of the temperature control apparatus, the temperature control method, and the recording medium. In this case, in the first and second aspects of the present invention, the element temperature model comprises a model which is determined to represent, in combination, a temperature change of the active element due to heat transfer between the active element and an exhaust gas held in contact with the active element and a temperature change of the active element due to heat transfer between the active element and the heater.

With the element temperature model thus determined, when the temperature of the active element is estimated, the temperature of the active element can be estimated taking into account both of a temperature change of the active element due to heat transfer between the active element and the exhaust gas held in contact therewith and a temperature change of the active element due to heat transfer between the active element and the heater. As a result, the accuracy of the estimated value of the temperature of the active element is further increased. By controlling the heater to equalize the temperature of the active element with a predetermined target temperature, using

the estimated value of the temperature of the active element, it is possible to control the temperature of the active element more stably at the target temperature.

To achieve the above object, a temperature control apparatus for an exhaust gas sensor according to a third aspect of the present invention is characterized by temperature estimating means for sequentially estimating the temperature of the active element based on a predetermined heater temperature model which is representative of a temperature change of the heater due to heat transfer between at least the heater and the active element, and heater control means for controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the heater from the temperature estimating means.

Similarly, to achieve the above object, a temperature control method for an exhaust gas sensor according to the third aspect of the present invention is characterized by, while sequentially estimating the temperature of the active element based on a predetermined heater temperature model which is representative of a temperature change of the heater due to heat transfer between at least the heater and the active element, controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the heater.

To achieve the above object, a recording medium storing a temperature control program for an exhaust gas sensor according to the third aspect of the present invention is characterized in that the temperature control program comprises a temperature estimating program for enabling the computer to perform a process of sequentially estimating the temperature of the heater based on a predetermined heater temperature model which is representative of a temperature change of the heater due to heat transfer between at least the heater and the active element, and a heater control program for enabling the computer to perform a process of controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the heater.

According to the third aspect of the present invention, the heater temperature model is representative of a temperature change of the heater due to heat transfer between at least the heater and the active element. Therefore, when the temperature of the heater is estimated based on the heater temperature model, the temperature of the heater can be estimated taking into account a temperature change of the heater due to heat transfer between the heater and the active element. As a result, the accuracy of the estimated value of the temperature of the heater is increased. By controlling the heater to equalize the tem-

perature of the heater with a predetermined target tempera-
ture (desired temperature), using the estimated value of
the temperature of the heater, it is possible to control
the temperature of the heater stably at the target tempera-
ture. Generally, the temperature of the heater and the
temperature of the active element are highly correlated to
each other in a steady state wherein their temperatures are
substantially constant. Therefore, since the temperature
of the heater can be controlled stably at the target tem-
perature as described above, the temperature of the active
element can indirectly be controlled stably at a tempera-
ture corresponding to the target temperature for the
heater.

To achieve the above object, a temperature con-
trol apparatus for an exhaust gas sensor according to a
fourth aspect of the present invention is characterized by
temperature estimating means for sequentially estimating
the temperature of the heater based on a predetermined
heater temperature model which is representative of a tem-
perature change of the heater due to the supply of heating
energy to at least the heater, and heater control means for
controlling the heater to equalize the temperature of the
heater with a predetermined target temperature, using an
estimated value of the temperature of the heater from the
temperature estimating means.

Similarly, to achieve the above object, a temperature control method for an exhaust gas sensor according to the fourth aspect of the present invention is characterized by, while sequentially estimating the temperature of the heater based on a predetermined heater temperature model which is representative of a temperature change of the heater due to the supply of heating energy to at least the heater, controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the heater.

To achieve the above object, a recording medium storing a temperature control program for an exhaust gas sensor according to the fourth aspect of the present invention is characterized in that the temperature control program comprises a temperature estimating program for enabling the computer to perform a process of sequentially estimating the temperature of the heater based on a predetermined heater temperature model which is representative of a temperature change of the heater due to the supply of heating energy to at least the heater, and a heater control program for enabling the computer to perform a process of controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the heater.

According to the fourth aspect of the present invention, the heater temperature model is representative

of a temperature change of the heater due to the supply of
heating energy to at least the heater. Therefore, when the
temperature of the heater is estimated based on the heater
temperature model, the temperature of the heater can be es-
timated taking into account a temperature change of the
heater due to the supply of heating energy to the heater.
As a result, the accuracy of the estimated value of the
temperature of the heater is increased. By controlling the
heater to equalize the temperature of the heater with a
predetermined target temperature (desired temperature), us-
ing the estimated value of the temperature of the heater,
it is possible to control the temperature of the heater
stably at the target temperature. Thus, the temperature of
the active element can indirectly be controlled stably at a
temperature corresponding to the target temperature for the
heater.

Since the heater for the exhaust gas sensor is
usually an electric heater, the above heating energy is
usually electric power.

Both the third and fourth aspects of the present
invention should preferably be combined with respect to ei-
ther one of the temperature control apparatus, the tempera-
ture control method, and the recording medium. In this
case, in the third and fourth aspects of the present inven-
tion, the heater temperature model comprises a model which
is determined to represent, in combination, a temperature

change of the heater due to heat transfer between the heater and the active element and a temperature change of the heater due to the supply of heating energy to the heater.

With the heater temperature model thus determined, when the temperature of the heater is estimated, the temperature of the heater can be estimated taking into account both of a temperature change of the heater due to heat transfer between the heater and the active element, and a temperature change of the heater due to the supply of heating energy to the heater. As a result, the accuracy of the estimated value of the temperature of the active element is further increased, and hence the temperature of the heater can be controlled more stably at a predetermined target temperature. Since the temperature of the heater can further be stabilized, it is possible to control the temperature of the active element more stably at a temperature corresponding to the target temperature for the heater.

To achieve the above object, a temperature control apparatus for an exhaust gas sensor according to a fifth aspect of the present invention is characterized by temperature estimating means for sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of, in combination, a temperature change of the active element

due to heat transfer between the active element and an exhaust gas held in contact with the active element, and a temperature change of the active element due to heat transfer between the active element and the heater, and sequentially estimating the temperature of the heater based on a predetermined heater temperature model which is representative of, in combination, a temperature change of the heater due to heat transfer between the heater and the active element and a temperature change of the heater due to the supply of heating energy to the heater, and heater control means for controlling the heater to equalize the temperature of the active element with a predetermined target temperature, using an estimated value of the temperature of the active element and an estimated value of the temperature of the heater from the temperature estimating means.

Similarly, to achieve the above object, a temperature control method for an exhaust gas sensor according to the fifth aspect of the present invention is characterized by sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of, in combination, a temperature change of the active element due to heat transfer between the active element and an exhaust gas held in contact with the active element, and a temperature change of the active element due to heat transfer between the active element and the heater, and sequentially estimating the

temperature of the heater based on a predetermined heater
temperature model which is representative of, in combina-
tion, a temperature change of the heater due to heat trans-
fer between the heater and the active element and a tem-
perature change of the heater due to the supply of heating
energy to the heater, and controlling the heater to equal-
ize the temperature of the active element with a predeter-
mined target temperature, using an estimated value of the
temperature of the active element and an estimated value of
the temperature of the heater while estimating the tempera-
ture of the active element and the temperature of the
heater.

To achieve the above object, a recording medium
storing a temperature control program for an exhaust gas
sensor according to the fifth aspect of the present inven-
tion is characterized in that the temperature control pro-
gram comprises a temperature estimating program for ena-
bling the computer to perform a process of sequentially es-
timating the temperature of the active element based on a
predetermined element temperature model which is represen-
tative of, in combination, a temperature change of the ac-
tive element due to heat transfer between the active ele-
ment and an exhaust gas held in contact with the active
element, and a temperature change of the active element due
to heat transfer between the active element and the heater,
and sequentially estimating the temperature of the heater

based on a predetermined heater temperature model which is representative of, in combination, a temperature change of the heater due to heat transfer between the heater and the active element and a temperature change of the heater due to the supply of heating energy to the heater, and a heater control program for enabling the computer to perform a process of controlling the heater to equalize the temperature of the active element with a predetermined target temperature, using an estimated value of the temperature of the active element and an estimated value of the temperature of the heater.

According to the fifth aspect of the present invention, since the temperature of the active element is estimated based on the element temperature model according to a combination of the first and second aspects of the present invention, and the temperature of the heater is estimated based on the heater temperature model according to a combination of the third and fourth aspects of the present invention. By controlling the heater to equalize the temperature of the active element with a predetermined target temperature (desired temperature), using both the estimated value of the temperature of the active element and the estimated value of the temperature of the heater, it is possible to control the temperature of the active element effectively and stably at the target temperature.

Specifically, when the heater is controlled to equalize the temperature of the active element with the predetermined target temperature, inasmuch as the heater can be controlled taking into account not only the estimated value of the temperature of the active element as a controlled variable, but also the estimated value of the temperature of the heater which affects the temperature of the active element, the stability of a process of controlling the temperature of the active element at the target temperature can be increased.

According to the fifth aspect described above, the heater is controlled to equalize the temperature of the active element with the predetermined target temperature. Even when the heater is controlled to equalize the temperature of the heater with the predetermined target temperature according to the third and fourth aspects described above, it is possible to apply a process which is the same as the fifth aspect as described below.

To achieve the above object, a temperature control apparatus for an exhaust gas sensor according to a sixth aspect of the present invention is characterized by temperature estimating means for sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of, in combination, a temperature change of the active element due to heat transfer between the active element and an ex-

haust gas held in contact with the active element, and a temperature change of the active element due to heat transfer between the active element and the heater, and sequentially estimating the temperature of the heater based on a predetermined heater temperature model which is representative of, in combination, a temperature change of the heater due to heat transfer between the heater and the active element and a temperature change of the heater due to the supply of heating energy to the heater, and heater control means for controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the active element and an estimated value of the temperature of the heater from the temperature estimating means.

Similarly, to achieve the above object, a temperature control method for an exhaust gas sensor according to the sixth aspect of the present invention is characterized by sequentially estimating the temperature of the active element based on a predetermined element temperature model which is representative of, in combination, a temperature change of the active element due to heat transfer between the active element and an exhaust gas held in contact with the active element, and a temperature change of the active element due to heat transfer between the active element and the heater, and sequentially estimating the temperature of the heater based on a predetermined heater

temperature model which is representative of, in combina-
tion, a temperature change of the heater due to heat trans-
fer between the heater and the active element and a tem-
perature change of the heater due to the supply of heating
energy to the heater, and controlling the heater to equal-
ize the temperature of the heater with a predetermined tar-
get temperature, using an estimated value of the tempera-
ture of the active element and an estimated value of the
temperature of the heater while estimating the temperature
of the active element and the temperature of the heater.

To achieve the above object, a recording medium
storing a temperature control program for an exhaust gas
sensor according to the sixth aspect of the present inven-
tion is characterized in that the temperature control pro-
gram comprises a temperature estimating program for ena-
bling the computer to perform a process of sequentially es-
timating the temperature of the active element based on a
predetermined element temperature model which is represen-
tative of, in combination, a temperature change of the ac-
tive element due to heat transfer between the active ele-
ment and an exhaust gas held in contact with the active
element, and a temperature change of the active element due
to heat transfer between the active element and the heater,
and sequentially estimating the temperature of the heater
based on a predetermined heater temperature model which is
representative of, in combination, a temperature change of

the heater due to heat transfer between the heater and the active element and a temperature change of the heater due to the supply of heating energy to the heater, and a heater control program for enabling the computer to perform a process of controlling the heater to equalize the temperature of the heater with a predetermined target temperature, using an estimated value of the temperature of the active element and an estimated value of the temperature of the heater.

According to the sixth aspect of the present invention, since the temperatures of the active element and the heater are estimated in exactly the same manner as with the fifth aspect described, the estimated values of the temperatures thereof are accurately determined. By controlling the heater to equalize the temperature of the heater with the predetermined target temperature (desired temperature), using both the estimated value of the temperature of the active element and the estimated value of the temperature of the heater, the temperature of the heater can be controlled effectively and stably at the target temperature.

Specifically, when the heater is controlled to equalize the temperature of the heater with the predetermined target temperature, inasmuch as the heater can be controlled taking into account not only the estimated value of the temperature of the heater as a controlled variable,

but also the estimated value of the temperature of the active element which affects the temperature of the heater, the stability of a process of controlling the temperature of the heater at the target temperature can be increased. Hence, the temperature of the active element can be controlled with high stability at a temperature corresponding to the target temperature for the heater.

In the first aspect of the present invention which uses the element temperature model taking into account heat transfer between the active element and the exhaust gas for estimating the temperature of the active element, the element temperature model should preferably comprise a model which is representative of a change per predetermined time in the temperature of the active element as including a temperature change component depending on the difference between at least the temperature of the active element and the temperature of the exhaust gas held in contact with the active element. In the control apparatus according to the second aspect, the temperature estimating means should preferably sequentially estimate a temperature change of the active element based on the element temperature model, and accumulatively add an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element. Similarly, in the control method according to the second

aspect, while sequentially estimating a temperature change of the active element based on the element temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element. In the recording medium according to the first aspect, the temperature estimating program should preferably comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the active element based on the element temperature model, and accumulatively adding an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element.

In the element temperature model according to the first aspect, a temperature change component (a temperature change component per predetermined time) depending on the difference between the temperature of the active element and the temperature of the exhaust gas held in contact with the active element means a temperature change component of the active element depending on heat transfer between the active element and the exhaust gas. Therefore, based on the element temperature model including the temperature change component, an estimated value of the temperature change per predetermined time of the active ele-

ment can be determined in a manner appropriately taking
into account heat transfer between the active element and
the exhaust gas. It is possible to accurately determine
the estimated value of the temperature of the active ele-
ment by accumulatively adding the estimated value of the
temperature change to an initial value which is set when
the internal combustion engine starts to operate (a pre-
dicted value of the temperature of the active element at
the time the internal combustion engine starts to operate).
Thus, the heater can well be controlled to equalize the
temperature of the active element with the predetermined
target temperature for thereby increasing the stability of
the temperature of the active element.

The above process of sequentially estimating the
temperature change per predetermined time of the active
element and accumulatively adding the estimated value to
the initial value can also be applied to the second aspect
of the present invention which uses the element temperature
model taking into account heat transfer between the active
element and the heater. Specifically, in the second aspect
of the present invention, the element temperature model
should preferably comprise a model which is representative
of a change per predetermined time in the temperature of
the active element as including a temperature change compo-
nent depending on the difference between at least the tem-
perature of the active element and the temperature of the

heater. In the control apparatus according to the second aspect of the present invention, the temperature estimating means should preferably sequentially estimate a temperature change of the active element based on the element temperature model, and accumulatively add an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element. In the control method according to the second aspect, while sequentially estimating a temperature change of the active element based on the element temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element. In the recording medium according to the second aspect, the temperature estimating program should preferably comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the active element based on the element temperature model, and accumulatively adding an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element.

In the element temperature model according to the second aspect, a temperature change component depending

on the difference between the temperature of the active element and the temperature of the heater means a temperature change component (a temperature change component per predetermined time) of the active element depending on heat transfer between the active element and the heater. Therefore, based on the element temperature model including the temperature change component, an estimated value of the temperature change per predetermined time of the active element can be determined in a manner appropriately taking into account heat transfer between the active element and the heater. It is possible to accurately determine the estimated value of the temperature of the active element by accumulatively adding the estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate (a predicted value of the temperature of the active element at the time the internal combustion engine starts to operate). Thus, the heater can well be controlled to equalize the temperature of the active element with the predetermined target temperature for thereby increasing the stability of the temperature of the active element.

The above process of sequentially estimating the temperature change per predetermined time of the active element and accumulatively adding the estimated value to the initial value can also be applied to a combination of the element temperature model according to the first aspect

and the element temperature model according to the second aspect. In this case, the element temperature model should preferably comprise a model which is representative of a change per predetermined time in the temperature of the active element as including a temperature change component depending on the difference between the temperature of the active element and the temperature of the exhaust gas held in contact with the active element, and a temperature change component depending on the difference between the temperature of the active element and the temperature of the heater. In the temperature control apparatus according to a combination of the first and second aspects, the temperature estimating means should preferably sequentially estimate a temperature change of the active element based on the element temperature model, and accumulatively add an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element. In the temperature control method according to a combination of the first and second aspects, while sequentially estimating a temperature change of the active element based on the element temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element.

In the recording medium according to a combination of the
first and second aspects, the temperature estimating pro-
gram should preferably comprise a program for enabling the
computer to perform a process of sequentially estimating a
temperature change of the active element based on the ele-
ment temperature model, and accumulatively adding an esti-
mated value of the temperature change to an initial value
which is set when the internal combustion engine starts to
operate, thereby estimating the temperature of the active
element.

With the above arrangement, an estimated value
of the temperature change per predetermined time of the ac-
tive element can accurately be determined in a manner ap-
propriately taking into account two types of heat transfer,
i.e., heat transfer between the active element and the ex-
haust gas and heat transfer between the active element and
the heater. It is possible to more accurately determine
the estimated value of the temperature of the active ele-
ment by accumulatively adding the estimated value of the
temperature change to an initial value which is set when
the internal combustion engine starts to operate (a pre-
dicted value of the temperature of the active element at
the time the internal combustion engine starts to operate).
Thus, the heater can well be controlled to equalize the
temperature of the active element with the predetermined

target temperature for thereby further increasing the stability of the temperature of the active element.

In the first and second aspects, when the temperature of the active element is estimated using the element temperature model which is representative of a temperature change per predetermined time of the active element, as described above, the temperature of the exhaust gas which is required to determine a temperature change per predetermined time of the active element based on the element temperature model, and the temperature of the heater are directly detected using temperature sensors (latest detected values). However, values estimated from appropriate parameters (latest estimated values) may be used as those temperatures.

The above process of using the element temperature model which is representative of a temperature change per predetermined time of the active element in order to estimate the temperature of the active element should preferably be performed also in the third or fourth aspect of the present invention which estimates the temperature of the heater or a combination of the third and fourth aspects. Specifically, in the third aspect described above, the heater temperature model should preferably comprise a model which is representative of a change per predetermined time in the temperature of the heater as including a temperature change component depending on the difference be-

tween the temperature of the heater and the temperature of the active element. In the control apparatus according to the third aspect, the temperature estimating means should preferably sequentially estimate a temperature change of the heater based on the heater temperature model, and accumulatively add an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater. In the control method according to the third aspect, while sequentially estimating a temperature change of the heater based on the heater temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater. In the recording medium according to the third aspect, the temperature estimating program should preferably comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the heater based on the heater temperature model, and accumulatively adding an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater.

In the fourth aspect described above, the heater temperature model should preferably comprise a model which

is representative of a change per predetermined time in the temperature of the heater as including a temperature change component depending on an amount of heating energy supplied to the heater. In the temperature control apparatus according to the fourth aspect, the temperature estimating means sequentially estimates a temperature change of the heater based on the heater temperature model, and accumulatively adds an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater. In the temperature control method according to the fourth aspect, while sequentially estimating a temperature change of the heater based on the heater temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater. In the recording medium according to the fourth aspect, the temperature estimating program should preferably comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the heater based on the heater temperature model, and accumulatively adds an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater.

        If the third aspect and the fourth aspect are
combined with each other, then the heater temperature model
should preferably comprise a model which is representative
of a change per predetermined time in the temperature of
the heater as including a temperature change component de-
pending on the difference between the temperature of the
heater and the temperature of the active element, and a
temperature change component depending on an amount of
heating energy supplied to the heater. In the temperature
control apparatus according to a combination of the third
and fourth aspects, the temperature estimating means should
preferably sequentially estimate a temperature change of
the heater based on the heater temperature model, and accu-
mulatively add an estimated value of the temperature change
to an initial value which is set when the internal combus-
tion engine starts to operate, thereby estimating the tem-
perature of the heater. In the temperature control method
according to a combination of the third and fourth aspects,
while sequentially estimating a temperature change of the
heater based on the heater temperature model, an estimated
value of the temperature change should preferably be accu-
mulatively added to an initial value which is set when the
internal combustion engine starts to operate, thereby esti-
mating the temperature of the heater. In the recording me-
dium according to a combination of the third and fourth as-
pects, the temperature estimating program should preferably

comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the heater based on the heater temperature model, and accumulatively adding an estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater.

If the heater temperature model which is representative of a temperature change per predetermined time of the heater is used, then in the heater temperature model, a temperature change component (a temperature change component per predetermined time) depending on the difference between the temperature of the heater and the temperature of the active element means a temperature change component of the heater depending on heat transfer between the heater and the active element. Furthermore, a temperature change component of the heater depending on the amount of heating energy supplied to the heater means a temperature change component (a temperature change component per predetermined time) of the heater depending on the supply of heating energy to the heater.

In the third aspect described above, therefore, an estimated value of a temperature change per predetermined time of the heater can be determined in a manner appropriately taking into account heat transfer between the heater and the active element based on the heater tempera-

ture model. Similarly, in the fourth aspect described above, an estimated value of a temperature change per predetermined time of the heater can be determined in a manner appropriately taking into account the supply of heating energy to the heater. In particular, if the third and fourth aspects are combined with each other, then an estimated value of a temperature change per predetermined time of the heater can be determined more accurately in a manner appropriately taking into account both heat transfer between the heater and the active element and the supply of heating energy to the heater. The estimated value of the temperature of the heater can thus be determined accurately by accumulatively adding the estimated value of the temperature change to an initial value which is set when the internal combustion engine starts to operate (a predicted value of the temperature of the heater at the time the internal combustion engine starts to operate). Thus, the heater can well be controlled to equalize the temperature of the heater with the predetermined target temperature for thereby increasing the stability of the temperature of the active element.

The temperature of the active element which is required to determine a temperature change of the heater per predetermined time based on the heater temperature model is directly detected using a temperature sensor (latest detected value). However, a value estimated from an

appropriate parameter (latest estimated value) may be used as the temperature of the active element. The amount of heating energy supplied to the heater, which is required to determine a temperature change of the heater, may be a value (latest value) of a control input (controlled variable) that is generated in controlling the heater as a quantity for determining the amount of heating energy supplied to the heater. Alternatively, if the heater is an electric heater, then a current flowing through and a voltage applied to the heater, for example, may be detected, and electric power supplied to the heater which is grasped from detected values (latest detected values) may be used as a quantity for determining the amount of heating energy supplied to the heater.

In the fifth and sixth aspects of the present invention which estimate both the temperature of the active element and the temperature of the heater, it is preferably to establish an element temperature model and a heater temperature model for estimating the temperature of the active element and the temperature of the heater in the same manner as described above. Specifically, in either one of the fifth and sixth aspects, the element temperature model should preferably comprise a model which is representative of a change per predetermined time in the temperature of the active element as including a temperature change component depending on the difference between the temperature of

the active element and the temperature of the exhaust gas held in contact with the active element, a temperature change component depending on the difference between the temperature of the active element and the temperature of the heater, and the heater temperature model should preferably comprise a model which is representative of a change per predetermined time in the temperature of the heater as including a temperature change component depending on the difference between the temperature of the heater and the temperature of the active element, and a temperature change component depending on an amount of heating energy supplied to the heater. In the temperature control apparatus according to the fifth or sixth aspect, the temperature estimating means should preferably sequentially estimate a temperature change of the active element based on the element temperature model, and accumulatively add an estimated value of the temperature change to an initial value of the temperature of the active element which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element, and should preferably sequentially estimate a temperature change of the heater based on the heater temperature model, and accumulatively adds an estimated value of the temperature change to an initial value of the temperature of the heater which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater.

- 40 -

In the temperature control method according to the fifth or sixth aspect, while sequentially estimating a temperature change of the active element based on the element temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value of the temperature of the active element which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element, and while sequentially estimating a temperature change of the heater based on the heater temperature model, an estimated value of the temperature change should preferably be accumulatively added to an initial value of the temperature of the heater which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater. In the recording medium according to the fifth or sixth aspect, the temperature estimating program should preferably comprise a program for enabling the computer to perform a process of sequentially estimating a temperature change of the active element based on the element temperature model, and accumulatively adding an estimated value of the temperature change to an initial value of the temperature of the active element which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the active element, and sequentially estimating a temperature change of the heater based on the heater temperature model, and accumulatively

adding an estimated value of the temperature change to an initial value of the temperature of the heater which is set when the internal combustion engine starts to operate, thereby estimating the temperature of the heater.

With the above arrangement, temperature changes per predetermined time of the active element and the heater can accurately be determined in a manner appropriately taking into account the application of heat to the active element and the heater. By accumulatively adding an estimated value of the temperature change per predetermined time of the active element to an initial value of the temperature of the active element which is set when the internal combustion engine starts to operate (a predicted value of the temperature of the active element at the time the internal combustion engine starts to operate), it is possible to accurately determine the estimated value of the temperature of the active element. Likewise, by accumulatively adding an estimated value of the temperature change per predetermined time of the heater to an initial value of the temperature of the active element which is set when the internal combustion engine starts to operate (a predicted value of the temperature of the heater at the time the internal combustion engine starts to operate), it is possible to accurately determine the estimated value of the temperature of the heater. Thus, the heater can well be controlled to equalize the temperature of the active element or the

heater with the target temperature for thereby effectively increasing the stability of the temperature of the active element.

In this case, the temperature of the heater which is required to determine a temperature change of the active element based on the element temperature model may be an estimated value (latest value) based on the heater element temperature model. Similarly, the temperature of the active element which is required to determine a temperature change of the heater based on the heater element temperature model may be an estimated value (latest value) based on the element temperature model. The temperature of the exhaust gas which is required to determine a temperature change of the active element based on the element temperature model may be either one of detected and estimated values, as with the first aspect described above. The amount of heating energy supplied to the heater, which is required to determine a temperature change of the heater based on the heater temperature model, may be a control input that is generated in controlling the heater as a quantity for determining the amount of heating energy supplied to the heater or electric power supplied to the heater which is grasped from detected values of a current flowing through and a voltage applied to the heater.

According to the present invention which estimates the temperature of the active element and the tem-

perature of the heater by accumulatively adding an esti-
mated value of a temperature change per predetermined time
to an initial value, in either one of the first through
sixth aspects described above, the initial value should
preferably be set depending on the atmospheric temperature
and/or the temperature of the internal combustion engine at
least when the internal combustion engine starts to oper-
ate. With this arrangement, an initial value of the tem-
perature of the active element and the temperature of the
heater when the internal combustion engine starts to oper-
ate can appropriately be established. If the period of
time in which the internal combustion engine is at rest is
long before it starts to operate, then it is preferable to
use the atmospheric temperature as the initial value. If
the period of time in which the internal combustion engine
is at rest is short, then it is preferable to use the en-
gine temperature as the initial value.

In the temperature control apparatus according
to the first aspect, the second aspect, or a combination of
the first and second aspects of the present invention, the
heater control means should preferably sequentially gener-
ate a control input which determines an amount of heating
energy supplied to the heater, depending on at least the
estimated value of the temperature of the active element
from the temperature estimating means, and control the
heater depending on the control input. In the temperature

control method according to the first aspect, the second
aspect, or a combination of the first and second aspects of
the present invention, while sequentially generating a con-
trol input which determines an amount of heating energy
supplied to the heater, depending on at least the estimated
value of the temperature of the active element, the heater
should preferably be controlled depending on the control
input. In the recording medium according to the first as-
pect, the second aspect, or a combination of the first and
second aspects of the present invention, the heater control
program should preferably comprise a program for enabling
the computer to perform a process of sequentially generat-
ing a control input which determines an amount of heating
energy supplied to the heater, depending on at least the
estimated value of the temperature of the active element,
and controlling the heater depending on the control input.

The control input thus generated includes a
feedback component depending on the estimated value of the
temperature of the active element as a control quantity.
Therefore, the heater is controlled according to a feedback
control process. The heater can thus well be controlled to
control the temperature of the active element at the prede-
termined target temperature, thereby appropriately keeping
the stability of the temperature of the active element.

In the temperature control apparatus according
to the third aspect, the fourth aspect, or a combination of

the third and fourth aspects of the present invention, the heater control means should preferably sequentially generate a control input which determines an amount of heating energy supplied to the heater, depending on at least the estimated value of the temperature of the heater from the temperature estimating means, and control the heater depending on the control input. In the temperature control method according to the third aspect, the fourth aspect, or a combination of the third and fourth aspects of the present invention, while sequentially generating a control input which determines an amount of heating energy supplied to the heater, depending on at least the estimated value of the temperature of the heater, the heater should preferably be controlled depending on the control input. In the recording medium according to the third aspect, the fourth aspect, or a combination of the third and fourth aspects of the present invention, the heater control program should preferably comprise a program for enabling the computer to perform a process of sequentially generating a control input which determines an amount of heating energy supplied to the heater, depending on at least the estimated value of the temperature of the heater, and controlling the heater depending on the control input.

The control input thus generated includes a feedback component depending on the estimated value of the temperature of the heater as a control quantity. There-

fore, the heater is controlled according to a feedback con-
trol process. The heater can thus well be controlled to
control the temperature of the heater at the predetermined
target temperature, thereby appropriately keeping the sta-
bility of the temperature of the active element.

In the temperature control apparatus according
to the fifth aspect or the sixth aspect of the present in-
vention, the heater control means should preferably sequen-
tially generate a control input which determines an amount
of heating energy supplied to the heater by adding an input
component depending on at least the estimated value of the
temperature of the active element from the temperature es-
timating means and the estimated value of the temperature
of the heater from the temperature estimating means, and
control the heater depending on the control input. In the
temperature control method according to the fifth aspect or
the sixth aspect of the present invention, while sequen-
tially generating a control input which determines an
amount of heating energy supplied to the heater by adding
an input component depending on at least the estimated
value of the temperature of the active element and the es-
timated value of the temperature of the heater, the heater
should preferably be controlled depending on the control
input. In the recording medium according to the fifth as-
pect or the sixth aspect of the present invention, the
heater control program should preferably comprise a program

for enabling the computer to perform a process of sequentially generating a control input which determines an amount of heating energy supplied to the heater by adding an input component depending on at least the estimated value of the temperature of the active element and the estimated value of the temperature of the heater, and controlling the heater depending on the control input.

In the fifth aspect, the control input thus generated includes a feedback component depending on the estimated value of the temperature of the active element as a control quantity and, in addition, a control input component depending on the estimated value of the temperature of the heater. In the sixth aspect, the control input includes a control input component depending on the estimated value of the temperature of the active element, in addition to a feedback component depending on the estimated value of the temperature of the heater as a control quantity. As a result, the stability of a process of controlling the heater for equalizing the temperature of the active element or the temperature of the heater at the target temperature can further be increased. Hence, the stability of the temperature of the active element is more effectively maintained.

According to the present invention, the exhaust gas sensor may comprise an O_2 sensor disposed downstream of a catalytic converter for purifying the exhaust gas, for

example. If the air-fuel ratio of the exhaust gas to keep
the output voltage of the O_2 sensor at a predetermined
level in order for the catalytic converter to perform its
desired exhaust gas purifying capability, the temperature
of the active element of the O_2 sensor should preferably be
controlled at a temperature equal to or higher than 750°C
(e.g., 800°C). In this case, when the heater is to be con-
trolled with a target temperature determined for the active
element, the target temperature may be set to a temperature
equal to or higher than 750°C (e.g., 800°C). When the
heater is to be controlled with a target temperature deter-
mined for the heater, the target temperature may be set to
a temperature equal to or higher than 850°C (e.g., 900°C).

Brief description of the drawings:

FIG. 1 is a block diagram of an apparatus ac-
cording to a first embodiment of the present invention;
FIG. 2 is a fragmentary cross-sectional view showing a
structure of an O_2 sensor (exhaust gas sensor) in the appa-
ratus shown in FIG. 1; FIG. 3 is a graph illustrative of
the output characteristics of the O_2 sensor shown in FIG.
2; FIG. 4 is a block diagram showing a functional arrange-
ment of a sensor temperature control means in the apparatus
shown in FIG. 1; FIG. 5 is a cross-sectional view showing a
processing operation of an exhaust temperature observer in
the sensor temperature control means shown in FIG. 4; FIG.

6 is a block diagram showing a functional arrangement of the exhaust temperature observer in the sensor temperature control means shown in FIG. 4; FIG. 7 is a block diagram showing a functional arrangement of a heater controller in the sensor temperature control means shown in FIG. 4; FIG. 8 is a flowchart of an overall processing sequence of the sensor temperature control means in the apparatus shown in FIG. 1; FIGS. 9 through 11 are flowcharts of subroutines of the flowchart shown in FIG. 8; and FIG. 12 is a block diagram showing a functional arrangement of a sensor temperature control means in an apparatus according to a second embodiment of the present invention.

Best mode for carrying out the invention:

A first embodiment of the present invention will be described below with reference to FIGS. 1 through 11. FIG. 1 shows in block form an overall arrangement of the apparatus according to the first embodiment of the present invention. In FIG. 1, an engine (an internal combustion engine) 1 mounted on an automobile, a hybrid vehicle, or the like combusts a mixture of fuel and air and generates an exhaust gas, which is discharged into the atmosphere through an exhaust passage 3 communicating with an exhaust port 2 of the engine 1. The exhaust passage 3 incorporates therein two catalytic converters 4, 5 disposed successively downstream for purifying the exhaust gas emitted from the

engine 1 and flowing through the exhaust passage 3. The
exhaust passage 3 includes a section upstream of the cata-
lytic converter 4 (between the exhaust port 2 and the cata-
lytic converter 4), a section between the catalytic con-
verters 4, 5, and a section downstream of the catalytic
converter 5. These sections of the exhaust passage 3 are
provided by respective exhaust pipes 6a, 6b, 6c each in the
form of a tubular passage-defining member.

Each of the catalytic converters 4, 5 contains a
catalyst 7 (three-way catalyst in the present embodiment).
The catalyst 7 has a passage-defining honeycomb structure
and allows the exhaust gas to flow therethrough. Though
the catalytic converters 4, 5 may be of a unitary structure
with two catalytic beds, each comprising a three-way cata-
lyst, disposed respectively in upstream and downstream re-
gions thereof.

In the present embodiment, the air-fuel ratio in
the exhaust gas emitted from the engine 1 is controlled in
order for the upstream catalytic converter 4, in particu-
lar, to have a good exhaust gas purifying capability (the
ability of the catalytic converter 4 to purify CO, HC, and
NOx). For controlling the air-fuel ratio in the exhaust
gas, an O_2 sensor 8 is mounted on the exhaust passage 3 be-
tween the catalytic converters 4, 5, i.e., on the exhaust
passage defined by the exhaust pipe 6b, and a wide-range
air-fuel ratio sensor 9 is mounted on the exhaust passage 3

upstream of the catalytic converter 4, i.e., on the exhaust passage defined by the exhaust pipe 6a.

The O_2 sensor 8 corresponds to an exhaust gas sensor according to the present invention. Basic structural details and characteristics of the O_2 sensor 8 will be described below. As shown in FIG. 2, the O_2 sensor 8 has an active element 10 (sensitive element) in the form of a hollow bottomed cylinder made primarily of a solid electrolyte permeable to oxygen ions, e.g., stabilized zirconia (ZrO_2 + Y_2O_3). The active element 10 has outer and inner surfaces coated with porous platinum electrodes 11, 12, respectively. The O_2 sensor 8 also has a rod-shaped ceramic heater 13 inserted as an electric heater into the active element 10 for heating the active element 10 for activation and controlling the temperature of the active element 10. The active element 10 is filled with air containing oxygen at a constant concentration, i.e., under a constant partial pressure, in a space around the ceramic heater 13. The O_2 sensor 8 is placed in a sensor casing 14 mounted on the exhaust pipe 6b such that the tip end of the active element 10 has its outer surface positioned in contact with the exhaust gas flowing in the exhaust pipe 6b.

The tip end of the active element 10 is covered with a tubular protector 15 which protects the active element 10 against the impingement of foreign matter thereon. The tip end of the active element 10 which is positioned in

the exhaust pipe 6b contacts the exhaust gas through a plurality of holes (not shown) defined in the protector 15.

The O_2 sensor 8 thus constructed operates as follows: An electromotive force depending on the concentration of oxygen in the exhaust gas is generated between the platinum electrodes 11, 12 based on the difference between the concentration of oxygen in the exhaust gas which is brought into contact with the outer surface of the tip end of the active element 10 and the concentration of oxygen in the air in the active element 10. The generated electromotive force is amplified by an amplifier (not shown), and then produced as the output voltage Vout from the O_2 sensor 8.

The output voltage Vout of the O_2 sensor 8 has characteristics (output characteristics) with respect to the concentration of oxygen in the exhaust gas or the air-fuel ratio in the exhaust gas which is recognized from the concentration of oxygen, as represented by a solid-line curve "a" (so-called "Z curve") in FIG. 3. The solid-line curve "a" represents the output characteristics of the O_2 sensor 8 when the temperature of the active element 10 is 800°C. The relationship between the temperature of the active element 10 and the output characteristics of the O_2 sensor 8 will be described later on.

As indicated by the curve "a" in FIG. 3, the output characteristics of the O_2 sensor 8 are generally of

such a nature that the output voltage Vout changes substantially linearly with high sensitivity with respect to the air-fuel ratio of the exhaust gas only when the air-fuel ratio represented by the concentration of oxygen in the exhaust gas is present in a narrow air-fuel ratio range Δ near a stoichiometric air-fuel ratio. In the air-fuel ratio range Δ (hereinafter referred to as "high-sensitivity air-fuel ratio range Δ"), the gradient of a change in the output voltage Vout with respect to a change in the air-fuel ratio, i.e., the gradient of the curve of the output characteristics of the O_2 sensor 8, is large. In an air-fuel ratio range richer than the high-sensitivity air-fuel ratio range Δ and an air-fuel ratio range leaner than the high-sensitivity air-fuel ratio range Δ, the gradient of a change in the output voltage Vout with respect to a change in the air-fuel ratio, i.e., the gradient of the curve of the output characteristics of the O_2 sensor 8, is smaller.

The wide-range air-fuel ratio sensor 9, which will not be described in detail below, comprises an air-fuel ratio sensor disclosed in Japanese laid-open patent publication No. 4-369471 by the applicant of the present application, for example. The wide-range air-fuel ratio sensor 9 is a sensor for generating an output voltage KACT which changes linearly with respect to the air-fuel ratio in the exhaust gas in an air-fuel ratio range wider than the O_2 sensor 8. The output voltage Vout of the O_2 sensor

8 and the output voltage KACT of the wide-range air-fuel ratio sensor 9 will hereinafter be referred to as "output Vout" and "output KACT", respectively.

As shown in FIG. 1, the apparatus according to the present embodiment also has a control unit 16 for controlling the air-fuel ratio in the exhaust gas and controlling the temperature of the active element 10 of the O_2 sensor 8. The control unit 16 comprises a microcomputer including a CPU, a RAM, and a ROM (not shown). For carrying out a control process to be described later on, the control unit 16 is supplied with the outputs Vout and KACT from the O_2 sensor 8 and the wide-range air-fuel ratio sensor 9, and also with data representing the rotational speed NE of the engine 1, the intake pressure PB (the absolute pressure in the intake pipe of the engine 1), and a detected value of the atmospheric temperature T_A, from sensors (not shown) combined with the engine 1. The ROM of the control unit 16 corresponds to a recording medium according to the present invention.

The control unit 16 has as its functional means an air-fuel ratio control means 17 for controlling the air-fuel ratio in the exhaust gas emitted from the engine 1, and a sensor temperature control means 18 for controlling the temperature of the active element 10 of the O_2 sensor 8.

The air-fuel ratio control means 17 controls the air-fuel ratio in the exhaust gas supplied from the engine 1 to the catalytic converter 4 in order to achieve a good purifying ability (purification rate) of the catalytic converter 4 to purify CO (carbon monoxide), HC (hydrocarbon), and NOx (nitrogen oxide). When the O_2 sensor 8 of the above output characteristics is disposed downstream of the catalytic converter 4, a good purifying ability of the catalytic converter 4 to purify CO, HC, and NOx can be achieved irrespective of the deteriorated state of the catalytic converter 4 by controlling the air-fuel ratio in the exhaust gas supplied to the catalytic converter 4, i.e., the air-fuel ratio in the exhaust gas upstream of the catalytic converter 4, to settle the output Vout of the O_2 sensor 8 at a certain predetermined value Vop (see FIG. 3).

Specifically, the air-fuel ratio control means 17 uses the predetermined value Vop as a target value for the output Vout of the O_2 sensor 8, and controls the air-fuel ratio in the exhaust gas supplied from the engine 1 to the catalytic converter 4 in order to settle and keep the output Vout of the O_2 sensor 8 at the target value Vop. Such an air-fuel ratio control process is carried out by determining a target air-fuel ratio in the exhaust gas supplied to the catalytic converter 4 according to a feedback control process in order to converge the output Vout of the O_2 sensor 8 to the target value Vop, and adjusting the

amount of fuel to be supplied to the engine 1 according to
a feedback control process in order to converge the output
KACT (a detected value of the air-fuel ratio) of the wide-
range air-fuel ratio sensor 9 to the target air-fuel ratio.
Specific details of the air-fuel ratio control process car-
ried by the air-fuel ratio control means 17 do not consti-
tute an essential feature of the present invention, and
will not be described below. The air-fuel ratio control
process carried by the air-fuel ratio control means 17 is
carried out as described in paragraphs [0071] - [0362] in
the specification of Japanese laid-open patent publication
No. 11-324767 or U.S. patent No. 6,188,953, for example.

The output characteristics of the O_2 sensor 8
change depending on the temperature of the active element
10 thereof. In FIG. 3, the solid-line curve "a", a broken-
line curve "b", a dot-and-dash-line curve "c", and a two-
dot-and-dash-line curve "d" represent the output character-
istics of the O_2 sensor 8 when the active element 10 has
temperatures of 800°C, 750°C, 700°C, and 600°C, respec-
tively. As can be seen from FIG. 3, if the temperature of
the active element 10 changes in a temperature range lower
than 750°C, then the gradient (sensitivity) of a change in
the output Vout of the O_2 sensor 8 in the vicinity of the
stoichiometric air-fuel ratio (the high-sensitivity air-
fuel ratio range Δ) and the level of the output Vout at
air-fuel ratios richer than the high-sensitivity air-fuel

ratio range Δ tend to change. If the temperature of the active element 10 is 750°C or higher, then a change in the output characteristics of the O_2 sensor 8 with respect to a change in the temperature of the active element 10 is so small that the output characteristics of the O_2 sensor 8 are substantially constant.

Since the output characteristics of the O_2 sensor 8 change depending on the temperature of the active element 10 as described above, the control properties (stability and quick response) of the air-fuel ratio control means 17 are likely to be lowered depending on the temperature of the active element 10. This is because in controlling the air-fuel ratio in the exhaust gas in order to keep the output Vout of the O_2 sensor 8 at the target value Vop, the output characteristics of the O_2 sensor 8 in the vicinity of the stoichiometric air-fuel ratio, i.e., the output characteristics of the O_2 sensor 8 in the high-sensitivity air-fuel ratio range Δ, are liable to greatly affect those control properties. The target value Vop for the output Vout of the O_2 sensor 8 to keep well the ability of the catalyst 7 of the catalytic converter 4 to purify the exhaust gas also changes depending on the temperature of the active element 10 in a temperature range lower than 750°C. Therefore, it is preferable to keep the temperature of the active element 10 of the O_2 sensor 8 basically at a constant level for the purpose of well controlling the air-air

ratio with the air-fuel ratio control means 17, i.e., controlling the output Vout of the O_2 sensor 8 at the target value Vop, and achieving a good purifying ability of the catalytic converter 4.

If the temperature of the active element 10 of the O_2 sensor 8 is 750°C or higher, then the output characteristics of the O_2 sensor 8 are substantially constant and stable. According to the inventors' knowledge, if the temperature of the active element 10 is kept at a temperature equal or higher than 750°C, e.g., 800°C, then the target value Vop for the output Vout of the O_2 sensor 8 to keep well the ability of the catalyst 7 of the catalytic converter 4 to purify the exhaust gas is present in an area denoted by Y on the curve "a" in FIG. 3, i.e., an inflection point Y where the gradient of the curve "a" representing the output characteristics of the O_2 sensor 8 switches from a larger value to a smaller value as the air-fuel ratio becomes richer. At this time, the air-fuel ratio can be controlled to keep the output Vout of the O_2 sensor 8 at the target value Vop. The reason for the above air-fuel fuel control appears to be that the sensitivity of the output Vout of the O_2 sensor 8 to the air-fuel ratio at the inflection point Y is neither excessively high nor small, but is appropriate.

According to the present embodiment, the sensor temperature control means 18 controls the ceramic heater 13

to keep the temperature of the active element 10 of the O_2 sensor 8 at a desired temperature which is basically equal to or higher than 750°C, e.g., 800°C. A control process carried out by the sensor temperature control means 18 will be described below.

As shown in FIG. 4, the sensor temperature control means 18 has as its major functions an exhaust temperature observer 19 for sequentially estimating an exhaust gas temperature Tgd in the exhaust passage 3 near the O_2 sensor 8, i.e., at an intermediate portion of the exhaust pipe 6b, an element temperature observer 20 (temperature estimating means) for estimating the temperature T_{O2} of the active element 10 of the O_2 sensor 8 and the temperature Tht of the ceramic heater 13 using the estimated value of the exhaust gas temperature Tgd, a target value setting means 21 for setting a target value R for the temperature of the active element 10, and a heater controller 22 (heater control means) for controlling energization of the ceramic heater 13, i.e., controlling the electric energy supplied to the ceramic heater 13, using the estimated values of the temperature T_{O2} of the active element 10 and the temperature Tht of the ceramic heater 13, the target value R, and the estimated value of the exhaust gas temperature Tgd.

In the present embodiment, the ceramic heater 13 is controlled for its energization (PWM control) by giving

a pulsed voltage to a heater energization circuit (not shown). The amount of electric energy supplied to the ceramic heater 13 is determined by the duty cycle DUT of the pulsed voltage (the ratio of the pulse duration to one period of the pulsed voltage). The heater controller 22 uses the duty cycle DUT of the pulsed voltage applied to the heater energization circuit as a control input (manipulated variable) for controlling the ceramic heater 13, and adjusts the duty cycle DUT to control the amount of electric energy supplied to the ceramic heater 13 and hence the amount of heat generated by the ceramic heater 13. The duty cycle DUT generated by the heater controller 22 is also used in a processing sequence of the element temperature observer 20.

According to the present embodiment, the portion of the exhaust passage 3 which extends from the exhaust port 2 of the engine 1 to the position where the O_2 sensor 8 is located, i.e., the exhaust passage 3 upstream of the O_2 sensor 8, is divided into a plurality of (four in the present embodiment) partial exhaust passageways 3a, 3b, 3c, 3d along the direction in which the exhaust passage 3 extends, i.e., the direction in which the exhaust gas flows. The exhaust temperature observer 19 estimates, in a predetermined cycle time (period), the temperature of the exhaust gas at the exhaust port 2 (the inlet of the exhaust passage 3) and the temperatures of the exhaust gas in the

respective partial exhaust passageways 3a, 3b, 3c, 3d, or specifically, the temperatures of the exhaust gas in the downstream ends of the respective partial exhaust passageways 3a, 3b, 3c, 3d, successively in the downstream direction. Of the partial exhaust passageways 3a, 3b, 3c, 3d, the partial exhaust passageways 3a, 3b are two partial exhaust passageways divided from the exhaust passage 3 upstream of the catalytic converter 4, i.e., the exhaust passage defined by the exhaust pipe 6a, the partial exhaust passageway 3c is a partial exhaust passageway extending from the inlet to outlet of the catalytic converter 4, i.e., the exhaust passage defined in the catalyst 7 in the catalytic converter 4, and the partial exhaust passageway 3d is a partial exhaust passageway extending from the outlet of the catalytic converter 4 to the position where the O_2 sensor 8 is located. The exhaust temperature observer 19 has its algorithm constructed as follows:

The temperature of the exhaust gas at the exhaust port 2 of the engine 1 basically depends on the rotational speed NE and the intake pressure PB of the engine 1 while the engine 1 is operating in a steady state in which the rotational speed NE and the intake pressure PB are kept constant. Therefore, the temperature of the exhaust gas at the exhaust port 2 can basically be estimated from detected values of the rotational speed NE and the intake pressure PB, which serve as parameters indicative of the operating

state of the engine 1, based on a predetermined map which has been established by way of experimentation, for example. If the operating state (the rotational speed NE and the intake pressure PB) of the engine 1 varies, then the temperature of the exhaust gas at the exhaust port 2 suffers a time lag or delay in the response to the exhaust gas temperature determined by the map (hereinafter referred to as "basic exhaust gas temperature TMAP(NE,PB)").

According to the present embodiment, the exhaust temperature observer 19 determines, in a predetermined cycle time (processing period), the basic exhaust gas temperature TMAP(NE,PB) from the detected values (latest detected values) of the rotational speed NE and the intake pressure PB of the engine 1 based on the map, and thereafter sequentially estimates an exhaust gas temperature Texg at the exhaust port 2 as a value which follows, with a time lag of first order, the basic exhaust gas temperature TMAP(NE,PB) as expressed by the following equation (1):

$$Texg(k) = (1-Ktex) \cdot (Texg(k-1) + Ktex \cdot TMAP(NE,PB)$$

$$\cdots (1)$$

where k represents the ordinal number of a processing period of the exhaust temperature observer 19, and Ktex a coefficient (lag coefficient) predetermined by way of experimentation or the like ($0 < Ktex < 1$). In the present embodiment, the intake pressure PB of the engine 1 serves as a parameter representative of the amount of intake air in-

troduced into the engine 1. Therefore, if a flow sensor is
used for directly detecting the amount of intake air intro-
duced into the engine 1, then the output of the flow sen-
sor, i.e., a detected value of the amount of intake air,
may be used instead of the detected value of the intake
pressure PB.

Using the estimated value of the exhaust gas
temperature Texg at the exhaust port 2, the temperatures of
the exhaust gas in the respective partial exhaust passage-
ways 3a, 3b, 3c, 3d are estimated as described below. For
illustrative purpose, a general heat transfer that occurs
when a fluid flows through a circular tube 3 (see FIG. 5)
which extends in the direction of a Z-axis in the atmos-
phere while exchanging heat with the tube wall of the cir-
cular tube 3 will be described below. It is assumed that
the fluid temperature Tg and the temperature Tw of the tube
wall (hereinafter referred to as "circular tube temperature
Tw") are functions Tg(t,z), Tw(t,z) of the time t and the
position z in the direction of the Z-axis, the thermal con-
ductivity of the tube wall of the circular tube 23 is infi-
nite in the radial direction and nil in the direction of
the Z-axis. It is also assumed that the heat transfer be-
tween the fluid and the tube wall of the circular tube 23
and the heat transfer between the tube wall of the circular
tube 23 and the external atmosphere are proportional to
their temperature differences according to the Newton law

of cooling. At this time, the following equations (2-1),
(2-2) are satisfied:

$$Sg \cdot \rho g \cdot Cg \cdot \left(\frac{\partial Tg}{\partial t} + V \cdot \frac{\partial Tg}{\partial z} \right) = \alpha 1 \cdot U \cdot (Tw - Tg) \qquad \cdots (2\text{-}1)$$

$$Sw \cdot \rho w \cdot Cw \cdot \frac{\partial Tw}{\partial t} = \alpha 1 \cdot U \cdot (Tg - Tw) + \alpha 2 \cdot U \cdot (TA - Tw) \cdots (2\text{-}2)$$

where Sg, ρg, Cg represent the density and specific heat of

the fluid and the cross-sectional area of the fluid pas-

sage, respectively, Sw, ρw, Cw the density, specific heat,

and cross-sectional area of the tube wall of the circular

tube 23, respectively, V the speed of the fluid flowing

through the circular tube 23, T_A the atmospheric tempera-

ture outside of the circular tube 23, U the inner circum-

ferential length of the circular tube 23, α_1 the heat

transfer coefficient between the fluid and the tube wall of

the circular tube 23, and α_2 the heat transfer coefficient

between the tube wall of the circular tube 23 and the at-

mosphere. It is assumed that the atmospheric temperature

T_A is kept constant around the circular tube 23.

The above equations (2-1), (2-2) are modified

into the following equations (3-1), (3-2):

$$\frac{\partial Tg}{\partial t} = -V \cdot \frac{\partial Tg}{\partial z} + a \cdot (Tw - Tg) \qquad \cdots (3\text{-}1)$$

$$\frac{\partial Tw}{\partial t} = b \cdot (Tg - Tw) + c \cdot (TA - Tw) \qquad \cdots (3\text{-}2)$$

where a, b, c represent constants, a = $\alpha_1 \cdot U / (Sg \cdot \rho g \cdot Cg)$, b =

$\alpha_1 \cdot U / (Sw \cdot \rho w \cdot Cw)$, c = $\alpha_2 \cdot U / (Sw \cdot \rho w \cdot Cw)$.

The first term on the right side of the equation

(3-1) is a shifting flow term representing a time-dependent

rate of change of the fluid temperature Tg (a change in the

temperature per unit time) depending on the temperature
gradient in the flowing direction of the fluid and the
speed of the fluid in a position z. The second term on the
right side of the equation (3-1) is a heat transfer term
representing a time-dependent rate of change of the fluid
temperature Tg (a change in the temperature per unit time)
depending on the difference between the fluid temperature
Tg and the circular tube temperature Tw in the position z,
i.e., a time-dependent rate of change of the fluid tempera-
ture Tg which is caused by the heat transfer between the
fluid and the tube wall of the circular tube 23. There-
fore, the equation (3-1) indicates that the time-dependent
rate $\partial Tg/\partial t$ of change of the fluid temperature Tg in the
position z depends on the temperature change component of
the shifting flow term and the temperature change component
of the heat transfer term, i.e., the sum of those tempera-
ture change components.

The first term on the right side of the equation
(3-2) is a heat transfer term representing a time-dependent
rate of change of the circular tube temperature Tw (a
change in the temperature per unit time) depending on the
difference between the circular tube temperature Tw and the
fluid temperature Tg in the position z, i.e., a time-
dependent rate of change of the circular tube temperature
Tw which is caused by the heat transfer between the fluid
and the tube wall of the circular tube 23 in the position

z. The second term on the right side of the equation (3-2)
is a heat radiation term representing a time-dependent rate
of change of the circular tube temperature Tw (a change in
the temperature per unit time) depending on the difference
between the circular tube temperature Tw and the atmos-
pheric temperature T_A outside of the circular tube 23 in
the position z, i.e., a time-dependent rate of change of
the circular tube temperature Tw depending on the heat ra-
diation from the tube wall of the circular tube 23 into the
atmosphere in the position z. The equation (3-2) indicates
that the time-dependent rate $\partial Tw/\partial t$ of change of the circu-
lar tube temperature Tw in the position z depends on the
temperature change component of the heat transfer term and
the temperature change component of the heat radiation
term, i.e., the sum of those temperature change components.

According to the calculus of finite differences,
the equations (3-1), (3-2) can be rewritten into the fol-
lowing equations (4-1), (4-2):

$$Tg(t+\Delta t,z) = Tg(t,z) - \frac{V \cdot \Delta t}{\Delta z} \cdot (Tg(t,z) - Tg(t,z-\Delta z)) \qquad \cdots (4-1)$$
$$+ a \cdot \Delta t \cdot (Tw(t,z) - Tg(t,z))$$

$$Tw(t+\Delta t,z) = Tw(t,z) + b \cdot \Delta t \cdot (Tg(t,z) - Tw(t,z)) \qquad \cdots (4-2)$$
$$+ c \cdot \Delta t \cdot (TA - Tw(t,z))$$

The above equations (4-1), (4-2) indicate that
if the fluid temperature Tg(t,z) and the circular tube tem-
perature Tw(t,z) in the position z at the time t, and the
fluid temperature Tg(t,z-Δz) in a position z-Δz which pre-
cedes the position z (upstream thereof) at the time t are

known, then the fluid temperature Tg(t+Δt,z) and the circu-
lar tube temperature Tw(t+Δt,z) in the position z at a next
time t+Δt can be determined, and that the fluid tempera-
tures Tg and the circular tube temperatures Tw in succes-
sive positions z+Δz, z+2Δz, ··· can be determined by solv-
ing the equations (4-1), (4-2) simultaneously in sequence
for those positions. Specifically, if initial values of
the fluid temperature Tg and the circular tube temperature
Tw (initial values at t = 0) are given in the positions z,
z+Δz, z+2Δz, ··· and the fluid temperature Tg(t,0) at an
origin (e.g., the inlet of the circular tube 23) in the di-
rection of the Z-axis of the circular tube 23 is given (it
is assumed that z-Δz = 0), then the fluid temperatures Tg
and the circular tube temperatures Tw in successive posi-
tions z, z+Δz, z+2Δz, ··· at successive times t, t+Δt,
t+2Δt, ··· can be calculated.

The fluid temperature Tg(t,z) in the position z
can be calculated by cumulatively adding (integrating), to
the initial value Tg(0,z), the temperature change component
depending on the fluid speed V and the temperature gradient
in the position z (the temperature change component repre-
sented by the second term of the equation (4-1)) and the
temperature change component depending on the difference
between the fluid temperature Tg and the circular tube tem-
perature Tw in the position z (the temperature change com-
ponent represented by the third term of the equation (4-

1)), at each given time interval. The fluid temperatures
in the other positions z+Δz, z+2Δz, $\cdots$ can similarly be
calculated. The circular tube temperature Tw(t,z) in the
position z can be calculated by cumulatively adding (inte-
grating), to the initial value Tw(0,z), the temperature
change component depending on the difference between the
fluid temperature Tg and the circular tube temperature Tw
in the position z (the temperature change component repre-
sented by the second term of the equation (4-2)) and the
temperature change component depending on the difference
between the circular tube temperature Tw and the atmos-
pheric temperature T_A in the position z (the temperature
change component represented by the third term of the equa-
tion (4-2)), at each given time interval.

In the present embodiment, the exhaust tempera-
ture observer 19 uses the model equations (4-1), (4-2) and
determines the temperatures of the exhaust gas in the re-
spective partial exhaust passageways 3a, 3b, 3c, 3d as fol-
lows:

Of the partial exhaust passageways 3a, 3b, 3c,
3d, each of the partial exhaust passageways 3a, 3b is de-
fined by the exhaust pipe 6a. In order to estimate the
temperatures of the exhaust gas in the partial exhaust pas-
sageways 3a, 3b, the temperature changes depending on the
speed of the exhaust gas and the temperature gradient
thereof (the temperature gradient in the direction in which

the exhaust gas flows), the heat transfer between the exhaust gas and the exhaust pipe 6a, and the heat radiation from the exhaust pipe 6a into the atmosphere are taken into account in the same manner as described above with respect to the circular tube 23.

An estimated value of the exhaust gas temperature Tga in the partial exhaust passageway 3a and an estimated value of the temperature Twa (hereinafter referred to as "exhaust pipe temperature Twa") of the exhaust pipe 6a in the partial exhaust passageway 3a are determined by respective model equations (5-1), (5-2), shown below, in each cycle time of the processing sequence of the exhaust temperature observer 19. An estimated value of the exhaust gas temperature Tgb in the partial exhaust passageway 3b and an estimated value of the exhaust pipe temperature Twb in the partial exhaust passageway 3b are determined by respective model equations (6-1), (6-2), shown below, in each cycle time of the processing sequence of the exhaust temperature observer 19. More specifically, the exhaust gas temperature Tga and the exhaust pipe temperature Twa that are determined by the equations (5-1), (5-2) represent estimated values of the temperatures in the vicinity of the downstream end of the partial exhaust passageway 3a. Likewise, the exhaust gas temperature Tgb and the exhaust pipe temperature Twb that are determined by the equations (6-1), (6-2) represent estimated values of the temperatures in the

vicinity of the downstream end of the partial exhaust pas-

sageway 3b.

$$Tga(k+1) = Tga(k) - Vg \cdot \frac{dt}{La} \cdot (Tga(k) - Texg(k)) + Aa \cdot dt \cdot (Twa(k) - Tga(k))$$

$$\cdots (5-1)$$

$$Twa(k+1)=Twa(k)+Ba \cdot dt \cdot (Tga(k)-Twa(k))+Ca \cdot dt \cdot (T_A(k)-Twa(k))$$

$$\cdots (5-2)$$

$$Tgb(k+1) = Tgb(k) - Vg \cdot \frac{dt}{Lb} \cdot (Tgb(k) - Tga(k)) + Ab \cdot dt \cdot (Twb(k) - Tgb(k))$$

$$\cdots (6-1)$$

$$Twb(k+1)=Twb(k)+Bb \cdot dt \cdot (Tgb(k)-Twb(k))+Cb \cdot dt \cdot (T_A(k)-Twb(k))$$

$$\cdots (6-2)$$

In the equations (5-1), (5-2), (6-1), (6-2), dt
represents the period (cycle time) of the processing se-
quence of the exhaust temperature observer 19, and corre-
sponds to Δt in the equations (4-1), (4-2). In the equa-
tions (5-1), (6-1), La, Lb represent the respective lengths
(fixed values) of the partial exhaust passageways 3a, 3b,
and correspond to Δz in the equation (4-1). Aa, Ba, Ca in
the equations (5-1), (5-2) and Ab, Bb, Cb in the equations
(6-1), (6-2) represent model coefficients corresponding re-
spectively to a, b, c in the equations (4-1), (4-2), and
the values of those model coefficients are set (identified)
in advance by way of experimentation or simulation. In the
equations (5-1), (6-1), Vg represents a parameter (to be
determined as described later on) indicative of the speed
of the exhaust gas, and corresponds to V in the equation
(4-1).

The exhaust gas temperature Texg(k) (the exhaust gas temperature at the exhaust port 2) which is required to calculate a new estimated value Tga(k+1) of the exhaust gas temperature Tga according to the equation (5-1) is basically of the latest value determined according to the equation (1). Similarly, the exhaust gas temperature Tga(k) (the exhaust gas temperature in the partial exhaust passageway 3a) which is required to calculate a new estimated value Tgb(k+1) of the exhaust gas temperature Tgb according to the equation (6-1) is basically of the latest value determined according to the equation (5-1). The atmospheric temperature $T_A(k)$ which is required in the calculation of the equations (5-2), (6-2) is of the latest value of the atmospheric temperature detected by an atmospheric temperature sensor (in the present embodiment, a sensor on the engine 1 is used for this atmospheric temperature sensor), not shown. In the present embodiment, the gas speed parameter Vg which is required in the calculation of the equations (5-1), (6-1) is of a value which is calculated from latest detected values of the rotational speed NE and the intake pressure PB according to the following equation (7):

$$Vg = \frac{NE}{NEBASE} \cdot \frac{PB}{PBBASE} \qquad \cdots (7)$$

where NEBASE, PBBASE represent a predetermined rotational speed and a predetermined intake pressure, which are set to, for example, the maximum rotational speed of the engine

1 and 760 mmHg ($\approx$ 101 kPa), respectively. The gas speed

parameter Vg calculated according to the equation (7) is

proportional to the speed of the exhaust gas, with Vg $\leq$ 1.

In the present embodiment, initial values

Tga(0), Twa(0), Tgb(0), Twb(0) of the estimated values for

the exhaust gas temperature Tga, the exhaust pipe tempera-

ture Twa, the exhaust gas temperature Tgb, and the exhaust

pipe temperature Twb are set to the atmospheric temperature

which is detected by the atmospheric temperature sensor

(not shown) when the engine 1 has started to operate (upon

an engine startup).

The partial exhaust passageway 3c is defined by

the catalyst 7 in the catalytic converter 4. The catalyst

7 generates heat by itself due to its own exhaust gas puri-

fying action (specifically, an oxidizing/reducing action),

and the amount of heat (the amount of heat per unit time)

generated by the catalyst 7 is substantially in proportion

to the speed of the exhaust gas. This is because as the

speed of the exhaust gas is higher, the exhaust gas compo-

nents reacting with the catalyst 7 per unit time increase.

According to the present embodiment, for esti-

mating the exhaust gas temperature in the partial exhaust

passageway 3c with high accuracy, the generation of heat by

the catalyst 7 in the catalytic converter 4 as well as the

temperature change depending on the speed and temperature

gradient of the exhaust gas, the heat transfer between the

exhaust gas and the catalyst 7, and the heat radiation from the catalyst 7 into the atmosphere are taken into account.

An estimated value of the exhaust gas temperature Tgc in the partial exhaust passageway 3c and an estimated value of the temperature Twc (hereinafter referred to as "catalyst temperature Twc") of the catalyst 7 which defines the partial exhaust passageway 3c are determined by respective model equations (8-1), (8-2), shown below, in each cycle time of the processing sequence of the exhaust temperature observer 19. More specifically, the exhaust gas temperature Tgc and the catalyst temperature Twc that are determined by the equations (8-1), (8-2) represent estimated values of the temperatures in the vicinity of the downstream end of the partial exhaust passageway 3a, i.e., in the vicinity of the outlet of the catalytic converter 4.

$$Tgc(k+1) = Tgc(k) - Vg \cdot \frac{dt}{Lc} \cdot (Tgc(k) - Tgb(k)) + Ac \cdot dt \cdot (Twc(k) - Tgc(k))$$

$$\cdots (8\text{-}1)$$

$$Twc(k+1) = Twc(k) + Bc \cdot dt \cdot (Tgc(k) - Twc(k))$$
$$+ Cc \cdot dt \cdot (TA(k) - Twc(k)) + Dc \cdot dt \cdot Vg \qquad \cdots (8\text{-}2)$$

In the equation (8-1), Lc represents the length (fixed value) of the partial exhaust passageway 3c, and corresponds to Δz in the equation (4-1). Ac, Bc, Cc in the equations (8-1), (8-2) represent model coefficients corresponding respectively to a, b, c in the equations (4-1), (4-2), and the values of those model coefficients are set (identified) in advance by way of experimentation or simulation. The fourth term on the right side of the equation

(8-2) represents a temperature change component of the catalyst 7 in the catalytic converter 4 due to the heating of the catalyst 7 by itself, i.e., the temperature change per period of the processing sequence of the exhaust temperature observer 19, and is proportional to the gas speed parameter Vg. As with Ac through Cc, Dc in the fourth term represents a model coefficient is set (identified) in advance by way of experimentation or simulation. Therefore, the equation (8-2) corresponds to the combination of the right side of the equation (4-2) with a temperature change component due to the heating of a passage-defining member (the catalyst 7).

dt, Vg in the equations (8-1), (8-2) have the same meanings and values as those in the equations (5-1) through (6-2). The value of T_A used in the calculation of the equation (8-2) is identical to those used in the equation (5-2), (6-2). In the present embodiment, the initial values Tgc(0), Twc(0) of the exhaust gas temperature Tgc and the catalyst temperature Twc are equal to the detected value of the atmospheric temperature at the time the engine 1 has started to operate, as with the equations (5-1) through (6-2).

The partial exhaust passageway 3d is defined by the exhaust pipe 6b similar to the exhaust pipe 6a which define the partial exhaust passageways 3a, 3b. The exhaust gas temperature Tgd in the partial exhaust passageway 3d

and the exhaust pipe temperature Twa of the exhaust pipe 6b, or more specifically the temperature at the downstream end of the partial exhaust passageway 3d, are determined respectively by the following equations (9-1), (9-2) which are similar to the equations (5-1) through (6-2):

$$Tgd(k+1) = Tgd(k) - Vg \cdot \frac{dt}{Ld} \cdot (Tgd(k) - Tgc(k)) + Ad \cdot dt \cdot (Twd(k) - Tgd(k))$$

$$\cdots (9-1)$$

$$Twd(k+1) = Twd(k) + Bd \cdot dt \cdot (Tgd(k) - Twd(k)) + Cd \cdot dt \cdot (T_A(k) - Twd(k))$$

$$\cdots (9-2)$$

In the equation (9-1), Ld represents the length (fixed value) of the partial exhaust passageway 3d, and corresponds to Δz in the equation (4-1). Ad, Bd, Cd in the equations (9-1), (9-2) represent model coefficients corresponding respectively to a, b, c in the equations (4-1), (4-2), and the values of those model coefficients are set (identified) in advance by way of experimentation or simulation.

dt, Vg in the equations (9-1), (9-2) have the same meanings and values as those in the equations (5-1) through (6-2). The value of T_A used in the calculation of the equation (9-2) is identical to those used in the equation (5-2), (6-2), (8-2). The initial values Tgd(0), Twd(0) of the exhaust gas temperature Tgd and the catalyst temperature Twd are equal to the detected value of the atmospheric temperature at the time the engine 1 has started to operate, as with the equations (5-1) through (6-2).

The processing sequence of the exhaust tempera-
ture observer 19, as described above, determines estimated
values of the exhaust gas temperatures Texe, Tga, Tgb, Tgc,
Tgd in the exhaust port 2 of the engine 1 and the partial
exhaust passageways 3a, 3b, 3c, 3d successively downstream
in each cycle time. The estimated value of the exhaust gas
temperature Tgd in the partial exhaust passageway 3d which
is located most downstream corresponds to the temperature
of the exhaust gas in the vicinity of the location of the
O_2 sensor 8. The estimated value of the exhaust gas tem-
perature Tgd is obtained as the estimated value of the ex-
haust gas temperature in the vicinity of the location of
the O_2 sensor 8.

The algorithm of the estimating process of the
exhaust temperature observer 19 is shown in block form in
FIG. 6. In FIG. 6, the model equation (1) is referred to
as an exhaust port thermal model 24, the model equations
(5-1), (5-2) and the model equations (6-1), (6-2) as pre-
CAT exhaust system thermal models 25, 26, respectively, the
model equations (8-1), (8-2) as an in-CAT exhaust system
thermal model 27, and the model equations (9-1), (9-2) as a
post-CAT exhaust system thermal model 28. As shown in FIG.
6, each of the thermal models 24 through 28 is supplied
with the detected values of the rotational speed NE and the
intake pressure PB of the engine 1. The detected values of
the rotational speed NE and the intake pressure PB which

are supplied to the exhaust port thermal model 24 are used
to determine the basic exhaust gas temperature TMAP, and
the detected values of the rotational speed NE and the in-
take pressure PB which are supplied to the exhaust system
thermal models 25 through 28 are used to determine the
value of the gas speed parameter Vg. Each of the thermal
models 24 through 28 is also supplied with the detected
value of the atmospheric temperature T_A. The pre-CAT ex-
haust system thermal model 25, the pre-CAT exhaust system
thermal model 26, the in-CAT exhaust system thermal model
27, and the post-CAT exhaust system thermal model 28 are
supplied with the estimated values of the exhaust gas tem-
peratures Texg, Tga, Tgb, Tgc, respectively, which are out-
putted from the higher-level thermal models 24, 25, 26, 27.
The post-CAT exhaust system thermal model 28 eventually
produces the estimated value of the exhaust gas temperature
Tgd in the vicinity of the location of the O_2 sensor 8.

In the present embodiment, the detected value
produced by the atmospheric temperature sensor on the en-
gine 1 is used to estimate the temperatures of the passage-
defining members (the exhaust pipe 6a, the catalyst 7 in
the catalytic converter 4, and the exhaust pipe 6b) which
define the partial exhaust passageways 3a, 3b, 3c, 3d.
However, the detected value produced by an atmospheric sen-
sor which is disposed outside of the exhaust passage 3 may

be used to estimate the temperatures of those passage-defining members.

The element temperature observer 20 will be described below. The element temperature observer 20 estimates the temperature T_{o2} of the active element 10 of the O_2 sensor 8 sequentially in given cycle times in view of the thermal transfer between the active element 10 and the exhaust gas held in contact therewith and the thermal transfer between the active element 10 and the ceramic heater 13 (hereinafter referred to simply as "heater 13") which heats the active element 10. The element temperature observer 20 also estimates the temperature Tht of the heater 13 in order to estimate the temperature T_{o2} of the active element 10. In estimating the temperature Tht of the heater 13, the element temperature observer 20 takes into account the heat transfer between the heater 13 and the active element 13 and also the heating of the heater 13 based on the electric energy supplied to the heater 13. The element temperature observer 20 has an estimating algorithm for estimating the temperature T_{o2} and the temperature Tht, which is constructed as follows:

The element temperature observer 20 determines an estimated value of the temperature T_{o2} of the active element 10 (hereinafter referred to as "element temperature T_{o2}") and an estimated value of the temperature Tht of the heater 13 (hereinafter referred to as "heater temperature

Tht") sequentially in given cycle times respectively according to the model equations (10-1), (10-2) described below. The equation (10-1) is the equation of an element temperature model, and the equation (10-2) is the equation of a heater temperature model.

$$T_{o2}(k+1) = T_{o2}(k) + Ax \cdot dt \cdot (Tgd(k) - T_{o2}(k)) + Bx \cdot dt \cdot (Tht(k) - T_{o2}(k))$$

$$\cdots (10-1)$$

$$Tht(k+1) = Tht(k) - Cx \cdot dt \cdot (Tht(k) - T_{o2}(k)) + Dx \cdot dt \cdot DUT(k)$$

$$\cdots (10-2)$$

The equation (10-1) indicates that the temperature change of the active element 10 in each cycle time depends on a temperature change component (the second term on the right side of the equation (10-1)) depending on the difference between the exhaust gas temperature Tgd in the vicinity of the location of the O2 sensor 8 (the exhaust gas temperature in the partial exhaust passageway 3d) and the element temperature T_{o2}, i.e., a temperature change component which is caused by the heat transfer between the active element 10 and the exhaust gas held in contact therewith, and a temperature change component (the third term on the right hand of the equation (10-1)) depending on the difference between the element temperature T_{o2} and the heater temperature Tht, i.e., a temperature change component which is caused by the heat transfer between the active element 10 and the ceramic heater 13, i.e., the sum of those temperature change components.

The equation (10-2) indicates that the temperature change of the heater 13 in each cycle time depends on a temperature change component (the second term on the right side of the equation (10-2)) depending on the difference between the element temperature T_{o2} and the heater temperature Tht, i.e., a temperature change component which is caused by the heat transfer between the active element 10 and the heater 13, and a temperature change component depending on the duty cycle DUT that is generated by the heat controller 22 as described later on, i.e., a temperature change component which is caused by the heating of the heater 13 based on the electric energy supplied thereto, i.e., the sum of those temperature change components.

In the equations (10-1), (10-2), Ax, Bx, Cx, Dx represent model coefficients whose values are set (identified) in advance by way of experimentation or simulation, and dt represents the period (cycle time) of the processing sequence of the element temperature observer 20. In the present embodiment, the period dt is set to the same value as the cycle time (represented by dt in the equations (5-1) through (9-2)) of the processing sequence of the exhaust temperature observer 19.

The duty cycle DUT(k) which is required in the calculation of the equation (10-2) is of the latest value of the duty cycle DUT that is calculated by the heater controller 22 as described later on. In the present embodi-

ment, the initial values $T_{O2}(0)$, Tht(0) of the element temperature TO2 and the heater temperature Tht are equal to the detected value of the atmospheric temperature at the time the engine 1 has started to operate.

The element temperature observer 20 sequentially calculates the estimated values of the element temperature T_{O2} and the heater temperature Tht according to the estimating algorithm described above.

The heater controller 22 will be described below. The heater controller 22 sequentially generates the duty cycle DUT as a control input (manipulated variable) for controlling the heater 13 according to an optimum predictive control algorithm, and controls the electric energy supplied to the heater 13 with the generated duty cycle DUT.

According to the present embodiment, attention is paid to the difference between the element temperature T_{O2} and a target value therefor, a change per given time in the difference (corresponding to a rate of change of the difference), and a change per given time in the heater temperature Tht (corresponding to a rate of change of the heater temperature Tht), and model equations for an object to be controlled by the heater controller 22 are introduced using the above differences and changes as state quantities relative to the object to be controlled by the heater con-

troller 22. The heater controller 22 has its algorithm constructed as described below.

First, model equations for the object to be controlled by the heater controller 22 will be described below. Changes ΔT_{02}, ΔTht per given time in the element temperature T_{02} and the heater temperature Tht are expressed by the following equations (11-1), (11-2) based on the respective model equations (10-1), (10-2) with respect to the element temperature observer 20:

$$
\begin{aligned}
\Delta T_{02}(k+1) &= \Delta T_{02}(k) + Ax \cdot dt \cdot (\Delta Tgd(k) - \Delta T_{02}(k)) \\
&\quad + Bx \cdot dt \cdot (\Delta Tht(k) - \Delta T_{02}(k)) \\
&= (1 - Ax \cdot dt - Bx \cdot dt) \cdot \Delta T_{02}(k) \\
&\quad + Ax \cdot dt \cdot \Delta Tgd(k) + Bx \cdot dt \cdot \Delta Tht(k)
\end{aligned}
\quad \cdots (11\text{-}1)
$$

$$
\begin{aligned}
\Delta Tht(k+1) &= \Delta Tht(k) - Cx \cdot dt \cdot (\Delta Tht(k) - \Delta T_{02}(k)) \\
&\quad + Dx \cdot dt \cdot \Delta DUT(k) \\
&= (1 - Cx \cdot dt) \cdot \Delta Tht(k) + Cx \cdot dt \cdot \Delta T_{02}(k) \\
&\quad + Dx \cdot dt \cdot \Delta DUT(k)
\end{aligned}
\quad \cdots (11\text{-}2)
$$

In the above equations (11-1), (11-2), $\Delta T_{02}(k)$ = $T_{02}(k+1) - T_{02}(k)$, $\Delta Tht(k) = Tht(k+1) - Tht(k)$, $\Delta Tgd(k) = Tgd(k+1) - Tgd(k)$, $\Delta DUT(k) = DUT(k+1) - DUT(k)$.

A target value for the element temperature T_{02} is represented by R, and the difference e between the element temperature T_{02} and the target value R, i.e., the difference in each cycle time (hereinafter referred to as "element temperature difference e"), is defined according to the following equation (12):

$$e(k) = T_{02}(k) - R(k)$$

$$\cdots (12)$$

A change Δe in the element temperature differ-
ence e in each cycle time (hereinafter referred to as "ele-
ment temperature difference change Δe") is expressed by the
following equation (13) based on the above equations (11-
1), (12):

$\Delta e(k+1) = \Delta T_{02}(k+1) - \Delta R(k+1)$

$\quad = (1-Ax \cdot dt-Bx \cdot dt) \cdot \Delta e(k) + Ax \cdot dt \cdot \Delta Tgd(k) + Bx \cdot dt \cdot \Delta Tht(k)$

$\quad\quad\quad - \Delta R(k+1) + (1-Ax \cdot dt-Bx \cdot dt) \cdot \Delta R(k)$

$$\cdots (13)$$

In the equation (13), $\Delta e(k) = e(k+1) - e(k)$,
$\Delta R(k) = R(k+1) - R(k)$. In deriving the equation (13), the
equation $\Delta T_{02} = \Delta e(k) + \Delta R(k)$ (based on the equation (12))
is employed.

The equation $\Delta T_{02} = \Delta e(k) + \Delta R(k)$ is applied to
the equation (11-2), and the resulting equation is modified
into the following equation (14):

$\quad\quad \Delta Tht(k+1) = (1-Cx \cdot dt) \cdot \Delta Tht(k) + Cx \cdot dt \cdot \Delta e(k)$

$\quad\quad\quad\quad\quad +Dx \cdot dt \cdot \Delta DUT(k) + Cx \cdot dt \cdot \Delta R(k) \cdots (14)$

If a state quantity vector $X0(k) = (e(k), \Delta e(k),$
$\Delta Tht(k))^T$ (T represents a transposition) is introduced,
then the following equation (15) is obtained from the equa-
tions (14), (15) and the equation $e(k+1) = e(k) + \Delta e(k)$:

$X0(k+1) = \Phi \cdot X0(k) + G \cdot \Delta DUT(k) + Gd \cdot \Delta Tgd(k) + Gr \cdot R0(k+1)$

$$\cdots (15)$$

where $X0(k) = (e(k), \Delta e(k), \Delta Tht(k))^T$,

$\quad\quad R0(k+1) = (\Delta R(k+1), \Delta R(k))^T$,

$$G = (0, 0, Dx \cdot dt)^T,$$

$$Gd = (0, Ax \cdot dt, 0)^T,$$

$$\Phi = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 - Ax \cdot dt - Bx \cdot dt & Bx \cdot dt \\ 0 & Cx \cdot dt & 1 - Cx \cdot dt \end{bmatrix}$$

$$Gr = \begin{bmatrix} 0 & 0 \\ -1 & 1 - Ax \cdot dt - Bx \cdot dt \\ 0 & Cx \cdot dt \end{bmatrix}$$

In the equation (15), R0, G, Gd represent vectors defined in the above definition clause, and Φ, Gr represent matrixes defined in the above definition clause.

The above equation (15) is a basic equation of the model of the object to be controlled by the heater controller 22.

In the above description, the period of the control process of the heater controller 22 is the same as the period dt of the processing sequences of the exhaust temperature observer 19 and the element temperature observer 20. Therefore, the period dt is used in the vectors G, Gd and the matrixes Φ, Gr in the equation (15). It is preferable to carry out the processing sequences of the exhaust temperature observer 19 and the element temperature observer 20 in a relatively short period (e.g., a period of 20 through 50 msec.) in order to increase the accuracy with which to estimate the temperatures. However, the period of the control process of the heater controller 22 may be longer than the period dt of the processing sequences of the exhaust temperature observer 19 and the element tem-

perature observer 20 because the response speed of a change in the element temperature in response to the control input (duty cycle DUT) is relatively low (several Hz in terms of frequencies). According to an optimum predictive control process to be described later on, since future values of the target value R of the element temperature T_{o2} need to be stored and held for a certain time, the storage capacity of a memory for storing the target value R becomes large if the period of the control process of the heater controller 22 is short.

According to the present embodiment, the period (cycle time) of the control process of the heater controller 22 is set to a value dtc (e.g., 300 through 500 msec.) longer than the period dt of the processing sequences of the exhaust temperature observer 19 and the element temperature observer 20.

In the present embodiment, the model equation of the object to be controlled by the heater controller 22 is rewritten from the equation (15) into the following equation (16), using the period dtc of the control process of the heater controller 22:

$$X0(n+1) = \Phi \cdot X0(n) + G \cdot \Delta DUT(n) + Gd \cdot \Delta Tgd(n) + Gr \cdot R0(n+1)$$

$$\cdots (16)$$

where $X0(n) = (e(n), \Delta e(n), \Delta Tht(n))^{T}$,

$R0(n+1) = (\Delta R(n+1), \Delta R(n))^{T}$,

$G = (0, 0, Dx \cdot dtc)^{T}$,

$$Gd = (0, Ax \cdot dtc, 0)^T,$$

$$\Phi = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 - Ax \cdot dtc - Bx \cdot dtc & Bx \cdot dtc \\ 0 & Cx \cdot dtc & 1 - Cx \cdot dtc \end{bmatrix}$$

$$Gr = \begin{bmatrix} 0 & 0 \\ -1 & 1 - Ax \cdot dtc - Bx \cdot dtc \\ 0 & Cx \cdot dtc \end{bmatrix}$$

The equation (16) is a model equation of the object to be controlled which is actually used in the algorithm of the control process of the heater controller 22. In the equation (16), n represents the ordinal number of the period dtc of the control process of the heater controller 22.

Using the above model equation, the algorithm of the control process of the heater controller 22, i.e., the algorithm of the optimum predictive control process, is constructed as follows: It is assumed that the target value R of the element temperature T_{o2} is set for the future until after Mr steps (until after a multiple by Mr of the period dtc of the control process of the heater controller 22), and the exhaust gas temperature Tgd which acts as a disturbance input is known in the future until after Md steps (until after a multiple by Md of the period dtc of the control process of the heater controller 22). The value Mr will be referred to as a target value predicting time Mr, and the value Md as an exhaust gas temperature predicting time Md. These predicting times Mr, Md are rep-

resented by integers whose unit is one period dtc of the control process of the heater controller 22.

A controller for generating a control input ΔDUT for minimizing the value of an evaluating function J0 according to the following equation (17) serves as an optimum predictive servo controller:

$$J0 = \sum_{n=-M+1}^{\infty} [X0^T(n) \cdot Q0 \cdot X0(n) + \Delta DUT^T(n) \cdot H0 \cdot \Delta DUT(n)] \qquad \cdots (17)$$

where M represents a larger one of the target value predicting time Mr and the exhaust gas temperature predicting time Md, i.e., M = max(Mr,Md), and Q0, H0 are weighted matrixes for adjusting the convergence of the state quantity vector X0 and the power (size) of the control input ΔDUT. Q0 represents a 3-row, 3-column diagonal matrix as X0 is a cubic matrix, and H0 is a Scalar quantity as ΔDUT is a Scalar quantity. In the present embodiment, in order to reduce the power consumption of the heater 13, Q0 is set to a unit matrix (a diagonal matrix whose all diagonal components are "1") and H0 is set to a value (e.g., 1000) greater than the diagonal components of the matrix Q0. The target value predicting time Mr is set to 20, for example, and the exhaust gas temperature predicting time Md is set to 10, for example, with the period of the control process of the heater controller 22 being in the range from 300 to 500 msec.

The control input ΔDUT for minimizing the value of the evaluating function according to the equation (17)

is expressed by the equation (18) given below. In the present embodiment, it is assumed that the exhaust gas temperature Tgd is maintained at the present value in the future until after Md steps.

$$\Delta DUT(n) = F0 \cdot X0(n) + \sum_{i=1}^{Mr} [Fr0(i) \cdot R0(n+i)] + Fdt \cdot \Delta Tgd(n) \quad \cdots (18)$$

In the equation (18), F0 in the first term on the right side represents a cubic row vector (Fs0, Fe0, Fx0), Fr0(i) (i = 1, 2, $\cdots$, Mr) in the second term (the term of $\sum$) on the right side represent quadratic row vectors (Fr01(i), Fr02(i)), and Fdt in the third term on the right side represents a Scalar quantity. They are expressed by the equations (19-1) through (19-3) given below. In the present embodiment, since it is assumed that the exhaust gas temperature Tgd is maintained at the present value in the future until after Md steps, Fdt in the third term of the right side represents a Scalar quantity. If Tgd in each step in the future can be detected or estimated, then the control input DUT can be determined using those Tgd. In such a case, Fdt represents a vector comprising elements (Md + 1 elements) in { } of the equation (19-3).

$$F0 \equiv (Fs0, \ Fe0, \ Fx0)$$
$$= - \ [H0 + G^T \cdot P \cdot G]^{-1} \cdot G^T \cdot P \cdot \Phi$$

$\cdots (19-1)$

$$Fr0(i) \equiv (Fr01(i), \ Fr02(i)) \quad (i = 1, \ 2, \ \cdots, \ Mr)$$
$$= - \ [H0 + G^T \cdot P \cdot G]^{-1} \cdot G^T \cdot (\zeta^T)^{i-1} \cdot P \cdot Gr$$

$\cdots (19-2)$

$$Fdt = \sum_{i=0}^{Md} \{ -[H0+G^T \cdot P \cdot G]^{-1} \cdot G^T \cdot (\zeta^T)^1 \cdot P \cdot Gd \} \qquad \cdots (19\text{-}3)$$

where P represents a matrix (a 3-row, 3-column matrix) satisfying the following Ricatti equation (20-1), and ζ represents a matrix (a 3-row, 3-column matrix) expressed by the following equation (20-2):

$$P = Q0 + \Phi^T \cdot P \cdot \Phi$$

$$- \Phi \cdot P \cdot G \cdot [H0+G^T \cdot P \cdot G]^{-1} \cdot G^T \cdot P \cdot \Phi \qquad \cdots (20\text{-}1)$$

$$\zeta = \Phi + G \cdot F0 \qquad \cdots (20\text{-}2)$$

G, Gr, Gd, and Φ in the equations (19-2) through (19-3) and the equations (20-1), (20-2) are defined in the definition clause for the equation (16), and H0, Q0 in those equations represent weighted matrixes of the evaluating function J0 according to the equation (17) (H0 is a Scalar quantity).

The second term (the term of $\sum$) on the right side of the equation (18) is rewritten using the components of Fr0, R0 (see the definition clauses for the equations (19-2), (16)), and then modified into the following equation (21):

$$\sum_{i=1}^{Mr} [Fr0(i) \cdot R0(n+i)] = \sum_{i=1}^{Mr} [Fr(i) \cdot \Delta R(n+1)] \qquad \cdots (21)$$

where

$$Fr(i) = \begin{cases} Fr02(1) & :i = 0 \\ Fr01(i)+Fr02(i+1) & :i = 1,2,\cdots,Mr-1 \\ Fr01(Mr) & :i = Mr \end{cases}$$

By putting the equation (21) into the equation (18) and rewriting the first term on the right side of the

equation (18) using the components of F0, X0 (see the definition clauses for the equations (19-1), (16)), the equation (18) is expressed by the following equation (22):

$$\Delta DUT(n) = Fs0 \cdot e(n) + Fe0 \cdot \Delta e(n) + Fx0 \cdot \Delta Tht(n)$$

$$+ \sum_{i=0}^{Mr} [Fr(i) \cdot \Delta R(n+i)] + Fdt \cdot \Delta Tgd(n)$$

$$\cdots (22)$$

Since the control input DUT(n) to be generated by the heater controller 22 is represented by the sum of its initial value DUT(0) and $\Delta DUT(1)$, $\Delta DUT(2)$, $\cdots$, $\Delta DUT(n)$ cumulatively added thereto, the following equation (23) is obtained from the above equation (22):

$$DUT(n) = Fs0 \cdot \sum_{j=1}^{n} e(j) + Fe0 \cdot e(n) + Fx0 \cdot Tht(n)$$

$$+ \sum_{i=0}^{Mr} [Fr(i) \cdot R(n+i)] + Fdt \cdot Tgd(n)$$

$$-Fe0 \cdot e(0) - Fx0 \cdot Tht(0)$$

$$- \sum_{i=0}^{Mr} [Fr(i) \cdot R(0+i)] - Fdt \cdot Tgd(0) + DUT(0)$$

$$\cdots (23)$$

By setting the initial value terms of the equation (23), i.e., the sixth term (the term of $Fe0 \cdot e(0)$) through the tenth term (DUT(0)), to "0", the following equation (24) is obtained as an equation for calculating the control input DUT(n) to be actually generated by the heater controller 22:

$$DUT(n) = Fs0 \cdot \sum_{j=1}^{n} e(j) + Fe0 \cdot e(n) + Fx0 \cdot Tht(n)$$

$$+ \sum_{i=0}^{Mr} [Fr(i) \cdot R(n+i)] + Fdt \cdot Tgd(n)$$

$$\cdots(24)$$

The equation (24) is a formula for calculating the control input DUT(n) (duty cycle) for controlling the heater 13 with the heater controller 22. Specifically, the heater controller 22 sequentially calculates the control input DUT(n) according to the equation (24) in each cycle time (period) of the control process of the heater controller 22, and applies a pulsed voltage having the duty cycle DUT(n) to the heater energization circuit (not shown) to adjust the electric energy supplied to the heater 13. The first through third terms (the term including $\sum e(j)$ through the term including Tht(n)) of the equation (24) represent a control input component (a feedback component which will hereinafter be referred to as "optimum F/B component Uopfb") depending on the element temperature difference e and the heater temperature Tht. The fourth term (the term of $\sum Fr(i) \cdot R(n+1)$) on the right side of the equation (24) represents a control input component (a feed-forward component which will hereinafter be referred to as "optimum target value F/F component Uopfr") depending on the target value. The fifth term (the term including Tgd(n)) represents a control input component (a feed-forward component which will hereinafter be referred to as "optimum disturbance F/F component Uopfd") depending on the exhaust gas temperature Tgd (which functions as a disturbance on the object to be controlled). The heater controller 22 which

determines DUT as a control input according to the equation
(24) is expressed in block form as shown in FIG. 7.

Fs0, Fe0, Fx0 which are required to determine
the control input DUT(n) according to the equation (24) are
of values calculated in advance according to the equation
(19-1). Fr(i) (i = 0, 1, ···, Mr) is of values calculated
in advance according to the equations (21), (19-2). Fdt is
of a value calculated in advance according to the equation
(19-3). These coefficients Fs0, Fe0, Fx0, Fr(i), Fdt may
not necessarily be of the values according to the defining
equations, but may be of values adjusted by way of simula-
tion or experimentation. Furthermore, the coefficients
Fs0, Fe0, Fx0, Fr(i), Fdt may be changed depending on the
element temperature, the heater temperature, etc.

The heater temperature Tht and the exhaust gas
temperature Tgd which are required in the calculation of
the equation (24) are of the latest estimated value of the
heater temperature Tht determined by the element tempera-
ture observer 20 and the latest estimated value of the ex-
haust gas temperature Tgd determined by the exhaust tem-
perature observer 19.

The element temperature difference e required in
the calculation of the equation (24) is calculated from the
latest estimated value of the element temperature T_{o2} de-
termined by the element temperature observer 20 and the
target value R which has been set in a cycle time prior to

the target value predicting time Mr by the target value
setting means 21.

The target value setting means 21 basically sets
a temperature (e.g., 800°C in the present embodiment) equal
to or higher than 750°C at which the output characteristics
of the O_2 sensor 8 are stably good, as the target value R
for the temperature of the active element 10 in the same
cycle time as the cycle time (period) of the processing se-
quence of the heater controller 22. In order to perform
the processing sequence of the heater controller 22 accord-
ing to the algorithm of the optimum predictive control
process, the target value setting means 21 sets the target
value R in each cycle time as a target value R(n+Mr) after
the target value predicting time Mr from the present cycle
time, and stores a series of target values R(n+Mr) for the
target value predicting time Mr. Specifically, the target
value setting means 21 stores Mr+1 target values R(n),
R(n+1), ···, R(n+Mr) while sequentially updating them. The
target value R used to determine the element temperature
difference e that is required in the calculation of the
equation (24) is the value R(n) set and stored by the tar-
get value setting means 21 as described above in the cycle
time prior to the target value predicting time Mr. The
target values R(n), R(n+1), ···, R(n+Mr) stored as de-
scribed above are used to determine the value of the fourth
term (the term of $\sum$ including R(n+i)) of the equation (24).

If the target value R of the element temperature T_{O2} is set to a high temperature such as 800°C from the start of operation of the engine 1, then the active element 10 tends to be damaged due to stresses caused by quick heating if water is applied to the active element 10 of the O_2 sensor 8 when the engine 1 starts to operate. In the present invention, therefore, until a certain time (e.g., 15 seconds) elapses from the start of operation of the engine 1, the target value setting means 21 sets the target value R of the element temperature T_{O2} to a temperature lower than 750°C, e.g., 600°C.

Overall operation of the apparatus, particularly, the sensor temperature control means 18, according to the present embodiment will be described below.

When the engine 1 starts to operate, the sensor temperature control means 18 executes a main routine shown in FIG. 8 in a predetermined cycle time. The period in which the main routine is executed is shorter than the period dt of the processing sequence of the element temperature observer 20 and hence shorter than the period dtc of the processing sequence of the target value setting means 21 and the heater controller 22.

The sensor temperature control means 18 acquires detected values of the rotational speed NE and the intake pressure PB of the engine 1 and the atmospheric temperature T_A in STEP1, and then determines the value of a countdown

timer COPC for measuring the time dtc of one period of the processing sequence of the target value setting means 21 and the heater controller 22 in STEP2. The value of the countdown timer COPC has been initialized to "0" at the time when the engine 1 starts to operate.

If COPC = 0, then the sensor temperature control means 18 newly sets the value of the countdown timer COPC to a timer setting time TM1 which corresponds to the period dtc of the control processes of the target value setting means 21 and the heater controller 22 in STEP3. Thereafter, the target value setting means 21 carries out a process of setting a target value R for the element temperature T_{O2} of the O_2 sensor 8 in STEP4, and the heater controller 22 carries out a process of calculating a duty cycle DUT of the heater 13 in STEP5. If COPC $\neq$ 0 in STEP2, then the sensor temperature control means 18 counts down the value of the countdown timer COPC in STEP6, and skips the processing in STEP4 and STEP5. Therefore, the processing in STEP4 and STEP5 is carried out at the period dtc determined by the timer setting time TM1.

The processing in STEP4 and STEP5 is specifically carried out as follows: First, the processing in STEP4 is carried out by the target value setting means 21 as shown in FIG. 9.

The target value setting means 21 compares the value of a parameter TSH representative of the time that

has elapsed from the start of the engine 1 with a predetermined value XTM in STEP4-1. If TSH ≤ XTM, i.e., if the engine 1 is in a state immediately after it has started to operate, then the target value setting means 21 sets the target value R for the element temperature T_{O2} to a low temperature (e.g., 600°C) in order to prevent damage to the active element 10 of the O_2 sensor 8 in STEP4-2. Specifically, the target value R that is set at this time is a target value R(n+Mr) after the target value predicting time Mr from the present.

If TSH > XTM in STEP4-1, then the target value setting means 21 sets the target value R for the element temperature T_{O2} from the present detected value (acquired in STEP1 shown in FIG. 8) of the atmospheric temperature T_A based on a predetermined table in STEP4-3. The target value R that is set at this time is basically a predetermined value (800°C in the present embodiment) equal to or higher than 750°C if the atmospheric temperature T_A is a normal temperature (e.g., $T_A \geq 0$°C). When the atmospheric temperature T_A is low (e.g., $T_A < 0$°C) as when the engine 1 is operating in a cold climate, if the target value R for the element temperature T_{O2} is a high temperature of 800°C, the temperature of the heater 13 is liable to be excessively high. In the present embodiment, when the temperature of the heater 13 becomes excessively high, the heater 13 is forcibly de-energized by an overheating prevention

process (described later on) to prevent itself from a fail-
ure. In STEP4-3, according to the present embodiment, when
the atmospheric temperature T_A is low (e.g., $T_A < 0°C$), the
target value R for the element temperature T_{O2} is set to a
value slightly lower than the normal value (e.g., $750°C \leq R$
$< 800°C$).

Specifically, as with the target value R set in
STEP4-2, the target value R set in STEP4-3 is a target
value R(n+Mr) after the target value predicting time Mr
from the present.

After having set the target value R (= R(n+Mr))
in STEP4-2 or STEP4-3, the target value setting means 21
updates the values of Mr+1 buffers RBF(0), RBF(1), $\cdots$,
RBF(Mr) for storing target values R for the target value
predicting time Mr in STEP4-4, STEP4-5. The processing in
STEP4 is now finished.

In STEP4-4, specifically, the Mr buffers RBF(j)
(j = 0, 1, $\cdots$, Mr-1) are updated from the values of RBF(j)
to the values of RBF(j+1), and the value held in the buffer
RBF(0) so far is erased. In STEP4-5, the buffer RBF(Mr) is
updated to the target value newly set in STEP4-2 or STEP4-
3. The values of the buffers RBF(0), RBF(1), $\cdots$, RBF(Mr)
thus updated correspond respectively to R(n), R(n+1), $\cdots$,
R(n+Mr) in the fourth term of the equation (24). The val-
ues of the buffers RBF(0), RBF(1), $\cdots$, RBF(Mr) have been
initialized to a predetermined value (e.g., the target

value set in STEP4-2) at the time the engine 1 has started
to operate.

The processing in STEP5 is carried out by the
heater controller 22 as shown in FIG. 10. The heater con-
troller 22 calculates an element temperature difference
$e(n) = T_{O2}(n) - RBF(0)$ between the present estimated value
$T_{O2}(n)$ of the element temperature T_{O2} and the value of the
buffer RBF(0) (= R(n)), i.e., the target value R set by the
target value setting means 21 prior to the target value
predicting time Mr in STEP5-1.

Then, the heater controller 22 determines the
values of flags F/A, F/B in STEP5-2. The flag F/A is set
to "0" or "1" in a limiting process (described later on)
for limiting the duty cycle DUT. The flag F/A which is set
to "1" means that the duty cycle DUT is forcibly limited to
a predetermined upper or lower limit value, and the flag
F/B which is set to "0" means that the duty cycle DUT is
not limited to the predetermined upper or lower limit value
(the upper limit value > DUT > the lower limit value). The
flag F/B is set to "1" when the heater 13 is forcibly de-
energized by the overheating prevention process. The flags
F/A, F/B are initially set to "0".

If F/A = F/B = 0 in STEP5-2, then the heater
controller 22 adds the present value of $\sum e(j)$ in the first
term of the equation (24) to the difference $e(n)$ calculated
in STEP5-1 in STEP5-4. In this manner, the difference $e(n)$

is cumulatively added (integrated) in each cycle time dtc of the processing sequence of the heater controller 22. The initial value of $\sum e(j)$ is "0".

If F/A = 1 or F/B = 1 in STEP5-2, then since the present value of the duty cycle DUT is not a normal value, the heater controller 22 skips the processing in STEP5-3, but goes to STEP5-4, holding the present value of $\sum e(j)$.

Then, the heater controller 22 calculates the equation (24) using the present value (latest value) of the element temperature difference $e(n)$ determined in STEP5-2 and the present accumulated value of $\sum e(j)$, thus calculating the present value $DUT(n)$ of the control input DUT for the heater 13 in STEP5-4. Specifically, the heater controller 22 calculates the duty cycle $DUT(n)$ according to the equation (24) from the present value of the difference $e(n)$ determined in STEP5-1, the present accumulated value $\sum e(j)$, the present estimated value $Tht(n)$ of the heater temperature Tht, the present values (= $R(n)$, $R(n+1)$, $\cdots$, $R(n+Mr)$) of the buffers RBF(0), RBF(1), $\cdots$, RBF(Mr), the present estimated value $Tgd(n)$ of the exhaust gas temperature Tgd (the exhaust gas temperature at the location of the O_2 sensor 8), and the values of predetermined coefficients Fs0, Fe0, Fx0, Fr(i) (i = 0, 1, $\cdots$, Mr), Fdt. When the engine 1 starts to operate, the estimated value of the heater temperature Tht and the estimated value of the exhaust gas temperature Tgd are set to the atmospheric tem-

perature T_A as an initial value which is detected at the start of the engine 1. These initial values of the heater temperature Tht and the exhaust gas temperature Tgd are used in the calculation of the equation (24) when the processing sequences of exhaust temperature observer 19 and the element temperature observer 20 are not executed. After the processing sequences of exhaust temperature observer 19 and the element temperature observer 20 are executed, the latest estimated values determined in the processing sequences of exhaust temperature observer 19 and the element temperature observer 20 are used in the calculation of the equation (24).

Then, the heater controller 22 carries out a limiting process for limiting the duty cycle DUT(n) calculated in STEP5-4 in STEP5-5 through STEP5-11. Specifically, the heater controller 22 determines whether the duty cycle DUT(n) is smaller than a predetermined lower limit value (e.g., "0") or not in STEP5-5. If DUT(n) < the lower limit value, then the heater controller 22 forcibly sets the value of DUT(n) to the lower limit value in STEP5-6. Thereafter, the value of the flag F/A (the flag used in STEP5-2) is set to "1" in STEP5-7.

If DUT(n) ≥ the lower limit value, then the heater controller 22 determines whether the duty cycle DUT(n) is greater than a predetermined upper limit value (e.g., 100 %) or not in STEP5-8. If DUT(n) > the upper

limit value, then the heater controller 22 forcibly sets the value of DUT(n) to the upper limit value in STEP5-9. Thereafter, the value of the flag F/A is set to "1" in STEP5-10. If the lower limit value ≤ DUT(n) ≤ the upper limit value, then the heater controller 22 holds the value of DUT(n), and sets the flag F/A to "0" in STEP5-11. The processing in STEP5 is not finished.

Control then returns to the main routine shown in FIG. 8. The sensor temperature control means 18 carries out the processing in STEP7 through STEP13. The processing in STEP7 through STEP13 represents a process of preventing the heater 13 from being overheated. In STEP7, the sensor temperature control means 18 determines whether or not the present estimated value (latest value) of the heater temperature Tht is equal to or higher than a predetermined upper limit value THTLMT (e.g., 930°C). In the present embodiment, if Tht ≥ THTLMT, the sensor temperature control means 18 forcibly de-energizes the heater 13 to prevent the heater 13 from being damaged. However, the estimated value of Tht may temporarily rise to a value equal to or higher than the upper limit value THTLMT due to a disturbance or the like. According to the present embodiment, therefore, the sensor temperature control means 18 forcibly de-energizes the heater 13 if the state in which Tht ≥ THTLMT has continued for a predetermined time (e.g., 3 seconds, hereinafter referred to as "heater OFF delay time").

If Tht < THTLMT in STEP7, then the sensor temperature control means 18 sets the value of a countdown timer TMHTOFF for measuring the heater OFF delay time to a predetermined value TM2 corresponding to the heater OFF delay time in STEP8. Since the sensor temperature control means 18 does not forcibly de-energize the heater 13 at this time, the sensor temperature control means 18 sets the value of the flag F/B (the flag used in STEP5-2 shown in FIG. 10) to "0" in STEP9.

If Tht ≥ THTLMT in STEP7, then the sensor temperature control means 18 counts down the value of the countdown timer TMHTOFF by "1" in STEP10. Then, the sensor temperature control means 18 determines whether the value of the countdown timer TMHTOFF is "0" or not, i.e., whether the heater OFF delay time TM2 has elapsed with Tht ≥ THTLMT or not in STEP11.

If TMHTOFF ≠ 0, then the sensor temperature control means 18 sets the flag F/B to "0" in STEP9. If TMHTOFF = 0, then the sensor temperature control means 18 forcibly sets the present value of the duty cycle DUT to "0" in STEP12, and then sets the value of the flag F/B to "1" in STEP13.

When the flag F/B is set to "0" in STEP9, the sensor temperature control means 18 applies a pulsed voltage to the heater energization circuit according to the present value of the duty cycle DUT (the latest value cal-

culated in STEP5), energizing the heater 13 with the electric energy depending on the duty cycle DUT. When the value of the flag F/B is set to "1" in STEP12, the sensor temperature control means 18 does not apply a pulsed voltage to the heater energization circuit, thus de-energizing the heater 13.

After having thus executed the processing in STEP7 through STEP13, i.e., the process of preventing the heater 13 from being overheated, the sensor temperature control means 18 determines the value of a countdown timer COBS for measuring the time dt of one period of the processing sequences of the exhaust temperature observer 19 and the element temperature observer 20 in STEP14. The value of the countdown timer COBS is initially set to "0" when the engine 1 has started to operate.

If COBS = 0, then the sensor temperature control means 18 newly sets the value of COBS to a timer setting time TM3 (shorter than TM1 in STEP3) which corresponds to the period dt of the processing sequences of the exhaust temperature observer 19 and the element temperature observer 20 in STEP15. Then, the exhaust temperature observer 19 carries out a process of estimating the exhaust gas temperature Tgd (the exhaust gas temperature in the vicinity of the location of the O_2 sensor 8), and the element temperature observer 20 carries out a process of estimating the element temperature T_{o2} (including a process of esti-

mating the heater temperature Tht) in STEP16. If COBS ≠ 0 in STEP14, the exhaust temperature observer 19 skips the processing in STEP15 and STEP16. The processing in STEP16 is therefore carried out at a period dt which is determined by the timer setting time TM3. The main routine shown in FIG. 8 is now finished.

The processing in STEP16 is specifically carried out as shown in FIG. 11. The exhaust temperature observer 19 successively carries out the processing in STEP16-1 through STEP16-6 to determine an estimated value of the exhaust gas temperature Tgd in the vicinity of the location of the O_2 sensor 8. In STEP16-1, the exhaust temperature observer 19 determines a gas speed parameter Vg according to the equation (7) using the present detected values (the latest values acquired in STEP1) of the rotational speed NE and the intake pressure PB of the engine 1. The gas speed parameter Vg is forcibly set to Vg = 1 if the result calculated by the equation (7) exceeds "1" due to an excessive rotational speed of the engine 1.

Then, the exhaust temperature observer 19 calculates an estimated value of the exhaust gas temperature Texg at the exhaust port 2 of the engine 1 according to the equation (1) in STEP16-2. Specifically, the exhaust temperature observer 19 determines a basic exhaust gas temperature TMAP(NE,PB) from the present detected values of the rotational speed NE and the intake pressure PB of the

engine 1 based on the predetermined map, and thereafter
calculates the right side of the equation (1) using the ba-
sic exhaust gas temperature TMAP(NE,PB), the present esti-
mated value Texg(k-1) (determined in STEP16-2 in the pre-
ceding cycle time) of the exhaust gas temperature Texg, and
the value of a predetermined coefficient Ktex, thus calcu-
lating a new estimated value Texg(k) of the exhaust gas
temperature Texg. In the present embodiment, while the en-
gine 1 is idling and also while the supply of fuel to the
engine 1 is being cut off, the basic exhaust gas tempera-
ture TMAP used in the calculation of the equation (1) is
set to predetermined values corresponding to the respective
engine operating states. When the engine 1 starts to oper-
ate, the atmospheric temperature T_A detected at this time
is set as an initial value Texg(0) of the estimated value
of the exhaust gas temperature Texg. When the equation (1)
is calculated for the first time after the engine 1 has
started to operate, the initial value Texg(0) is used as
the value of Texg(k-1).

Then, the exhaust temperature observer 19 calcu-
lates an estimated value of the exhaust gas temperature Tga
and an estimated value of the exhaust pipe temperature Twa
in the partial exhaust passageway 3a according to the re-
spective equations (5-1), (5-2) in STEP16-3. Specifically,
the exhaust temperature observer 19 determines a new esti-
mated value Tga(k+1) of the exhaust gas temperature Tga by

calculating the right side of the equation (5-1) using the present estimated value Tga(k) (determined in STEP16-3 in the preceding cycle time) of the exhaust gas temperature Tga, the present estimated value (determined in STEP16-3 in the preceding cycle time) of the exhaust pipe temperature Twa, the present estimated value of the exhaust gas temperature Texg previously calculated in STEP16-2, the present value of the gas speed parameter Vg calculated in STEP16-1, the value of the predetermined model coefficient Aa, and the value of the period dt of the processing sequence of the exhaust temperature observer 19.

The exhaust temperature observer 19 calculates a new estimated value Twa(k+1) of the exhaust pipe temperature Twa by calculating the right side of the equation (5-2) using the present estimated value Tga(k) (determined in STEP16-3 in the preceding cycle time) of the exhaust gas temperature Tga, the present estimated value (determined in STEP16-3 in the preceding cycle time) of the exhaust pipe temperature Twa, the values of the predetermined model coefficients Ba, Ca, and the value of the period dt of the processing sequence of the exhaust temperature observer 19.

When the engine 1 starts to operate, the atmospheric temperature T_A detected at this time is set as initial values Tga(0), Twa(0) of the estimated values of the exhaust gas temperature Tga and the exhaust pipe temperature Twa. When the equations (5-1), (5-2) are calculated

for the first time after the engine 1 has started to operate, these initial values Tga(0), Twa(0) are used as the respective values of Tga(k-1), Twa(k-1).

Then, the exhaust temperature observer 19 calculates an estimated value of the exhaust gas temperature Tgb and an estimated value of the exhaust pipe temperature Twb in the partial exhaust passageway 3b according to the respective equations (6-1), (6-2) in STEP16-4. Specifically, the exhaust temperature observer 19 determines a new estimated value Tgb(k+1) of the exhaust gas temperature Tgb by calculating the right side of the equation (6-1) using the present estimated value Tgb(k) (determined in STEP16-4 in the preceding cycle time) of the exhaust gas temperature Tgb, the present estimated value (determined in STEP16-4 in the preceding cycle time) of the exhaust pipe temperature Twb, the present estimated value of the exhaust gas temperature Tga previously calculated in STEP16-3, the present value of the gas speed parameter Vg calculated in STEP16-1, the value of the predetermined model coefficient Ab, and the value of the period dt of the processing sequence of the exhaust temperature observer 19.

The exhaust temperature observer 19 calculates a new estimated value Twb(k+1) of the exhaust pipe temperature Twb by calculating the right side of the equation (6-2) using the present estimated value Tgb(k) (determined in STEP16-4 in the preceding cycle time) of the exhaust gas

temperature Tgb, the present estimated value (determined in STEP16-4 in the preceding cycle time) of the exhaust pipe temperature Twb, the values of the predetermined model co-efficients Bb, Cb, and the value of the period dt of the processing sequence of the exhaust temperature observer 19.

When the engine 1 starts to operate, the atmospheric temperature T_A detected at this time is set as initial values Tgb(0), Twb(0) of the estimated values of the exhaust gas temperature Tgb and the exhaust pipe temperature Twb. When the equations (6-1), (6-2) are calculated for the first time after the engine 1 has started to operate, these initial values Tgb(0), Twb(0) are used as the respective values of Tgb(k-1), Twb(k-1).

Then, the exhaust temperature observer 19 calculates an estimated value of the exhaust gas temperature Tgc and an estimated value of the exhaust pipe temperature Twc in the partial exhaust passageway 3c according to the respective equations (8-1), (8-2) in STEP16-5. Specifically, the exhaust temperature observer 19 determines a new estimated value Tgc(k+1) of the exhaust gas temperature Tgc by calculating the right side of the equation (8-1) using the present estimated value Tgc(k) (determined in STEP16-5 in the preceding cycle time) of the exhaust gas temperature Tgc, the present estimated value (determined in STEP16-5 in the preceding cycle time) of the exhaust pipe temperature Twc, the present estimated value of the exhaust gas tem-

perature Tgb previously calculated in STEP16-4, the present
value of the gas speed parameter Vg calculated in STEP16-1,
the value of the predetermined model coefficient Ac, and
the value of the period dt of the processing sequence of
the exhaust temperature observer 19.

The exhaust temperature observer 19 calculates a
new estimated value Twc(k+1) of the catalyst temperature
Twc by calculating the right side of the equation (8-2) us-
ing the present estimated value Tgc(k) (determined in
STEP16-5 in the preceding cycle time) of the exhaust gas
temperature Tgc, the present estimated value (determined in
STEP16-5 in the preceding cycle time) of the catalyst tem-
perature Twc, the present value of the gas speed parameter
Vg calculated in STEP16-1, the values of the predetermined
model coefficients Bc, Cc, Dc, and the value of the period
dt of the processing sequence of the exhaust temperature
observer 19.

When the engine 1 starts to operate, the atmos-
pheric temperature T_A detected at this time is set as ini-
tial values Tgc(0), Twc(0) of the estimated values of the
exhaust gas temperature Tgc and the exhaust pipe tempera-
ture Twc. When the equations (8-1), (8-2) are calculated
for the first time after the engine 1 has started to oper-
ate, these initial values Tgc(0), Twc(0) are used as the
respective values of Tgc(k-1), Twc(k-1).

Then, the exhaust temperature observer 19 calcu-
lates an estimated value of the exhaust gas temperature Tgd
and an estimated value of the exhaust pipe temperature Twd
in the partial exhaust passageway 3d (near the location of
the O_2 sensor 8) according to the respective equations (9-
1), (9-2) in STEP16-6. Specifically, the exhaust tempera-
ture observer 19 determines a new estimated value Tgd(k+1)
of the exhaust gas temperature Tgd by calculating the right
side of the equation (9-1) using the present estimated
value Tgd(k) (determined in STEP16-6 in the preceding cycle
time) of the exhaust gas temperature Tgd, the present esti-
mated value (determined in STEP16-6 in the preceding cycle
time) of the exhaust pipe temperature Twd, the present es-
timated value of the exhaust gas temperature Tgc previously
calculated in STEP16-5, the present value of the gas speed
parameter Vg calculated in STEP16-1, the value of the pre-
determined model coefficient Ad, and the value of the pe-
riod dt of the processing sequence of the exhaust tempera-
ture observer 19.

The exhaust temperature observer 19 calculates a
new estimated value Twd(k+1) of the exhaust pipe tempera-
ture Twd by calculating the right side of the equation (9-
2) using the present estimated value Tgd(k) (determined in
STEP16-6 in the preceding cycle time) of the exhaust gas
temperature Tgd, the present estimated value (determined in
STEP16-6 in the preceding cycle time) of the exhaust pipe

temperature Twd, the values of the predetermined model co-
efficients Bd, Cd, and the value of the period dt of the
processing sequence of the exhaust temperature observer 19.

When the engine 1 starts to operate, the atmos-
pheric temperature T_A detected at this time is set as ini-
tial values Tgd(0), Twd(0) of the estimated values of the
exhaust gas temperature Tgd and the exhaust pipe tempera-
ture Twd. When the equations (9-1), (9-2) are calculated
for the first time after the engine 1 has started to oper-
ate, these initial values Tgd(0), Twd(0) are used as the
respective values of Tgd(k-1), Twd(k-1).

Then, the element temperature observer 20 exe-
cutes the processing in STEP16-7 to determine estimated
values of the element temperature T_{o2} of the O_2 sensor 8 and
the heater temperature Tht according to the equations (10-
1), (10-2). Specifically, the element temperature observer
20 determines a new estimated value $T_{o2}(k+1)$ of the device
temperature T_{o2} by calculating the right side of the equa-
tion (10-1) using the present estimated value $T_{o2}(k)$ (de-
termined in STEP16-7 in the preceding cycle time) of the
element temperature T_{o2}, the present estimated value Tht(k)
(determined in STEP16-7 in the preceding cycle time) of the
heater temperature Tht, the present estimated value of the
exhaust gas temperature Tgd previously calculated in STEP6-
6, the values of the predetermined model coefficients Ax,
Bx, and the value of the period dt (= the period of the

of the processing sequence of the exhaust temperature ob-
server 19) of the processing sequence of the element tem-
perature observer 20.

Then, the element temperature observer 20 deter-
mines a new estimated value $Tht(k+1)$ of the heater tempera-
ture Tht by calculating the right side of the equation (10-
2) using the present estimated value $T_{O2}(k)$ (determined in
STEP16-7 in the preceding cycle time) of the element tem-
perature T_{O2}, the present estimated value $Tht(k)$ (deter-
mined in STEP16-7 in the preceding cycle time) of the
heater temperature Tht, the present value $DUT(k)$ of the
duty cycle DUT, the values of the predetermined model coef-
ficients Cx, Dx, and the value of the period dt of the
processing sequence of the element temperature observer 20.

When the engine 1 starts to operate, the atmos-
pheric temperature T_A detected at this time is set as ini-
tial values $T_{O2}(0)$, $Tht(0)$ of the estimated values of the
element temperature T_{O2} and the heater temperature Tht.
When the equations (10-1), (10-2) are calculated for the
first time after the engine 1 has started to operate, these
initial values $T_{O2}(0)$, $Tht(0)$ are used as the respective
values of $T_{O2}(k-1)$, $Tht(k-1)$. The duty cycle $DUT(k)$ used
in the equation (10-2) is basically of the latest value de-
termined by the heater controller 22 in STEP5. However, if
the value of the duty cycle DUT is limited in STEP12 to de-

energize the heater 13, then the limited value of the duty cycle DUT is used in the equation (10-2).

The above processing sequence of the sensor temperature control means 18 controls the electric energy supplied to the heater 13 of the O_2 sensor 8 in order to keep the element temperature T_{O2} of the O_2 sensor 8 at the target value R. Except immediately after the engine 1 has started to operate and when the atmospheric temperature T_A is considerably low, the target value R is normally set to 800°C. As a result, the output characteristics of the O_2 sensor 8 can be maintained stably as the characteristics suitable for controlling the air-fuel ratio of the engine 1, i.e., for controlling the air-fuel ratio thereof for the catalytic converter 4 to perform a better exhaust purifying capability, and the air-fuel ratio of the engine 1 can well be controlled to allow the catalytic converter 4 to perform a better exhaust purifying capability.

According to the present embodiment, the temperature T_{O2} of the O_2 sensor 8 and the heater temperature Tht are estimated by the element temperature observer 20. At this time, the temperature T_{O2} is sequentially estimated based on the model equation (10-1) which is constructed in view of a temperature change depending on the heat transfer between the active element 10 and the heater 13 and a temperature change depending on the heat transfer between the active element 10 and the exhaust gas in the vicinity of

the location where the O_2 sensor 8 is located (the exhaust gas held in contact with the active element 10). The heater temperature Tht is sequentially estimated based on the model equation (10-2) which is constructed in view of a temperature change depending on the heat transfer between the active element 10 and the heater 13 and a temperature change due to the electric power supplied to the heater 13, i.e., a temperature change depending on the duty cycle DUT which determines the amount of electric power supplied to the heater 13.

As a result, the element temperature T_{O2} and the heater temperature Tht can be estimated in a manner taking into account the application of heat to the active element 10 and the heater 13 appropriately, so that the estimated values of those temperatures have a sufficiently high level of accuracy.

The duty cycle DUT as a control input for the heater 13 is calculated as including a control input component (the first term (the term including $\sum e(j)$) and the second term (the term including $e(n)$) of the equation (24)) depending on the estimated value of the element temperature T_{O2} and also a control input component (the third term of the equation (24) depending on the estimated value of the heater temperature Tht. Therefore, combined with the fact that the accuracy of the estimated values of the element temperature T_{O2} and the heater temperature Tht is suffi-

ciently high, the element temperature T_{O2} can stably be controlled reliably at a desired target value R.

According to the present embodiment, the duty cycle DUT is calculated as including, in addition to a control input component depending on the element temperature T_{O2} and the heater temperature Tht, a control input component depending on the estimated value of the exhaust gas temperature Tgd which acts as a disturbant factor for varying the element temperature T_{O2}, i.e., the optimum disturbance value F/F component Uopfd. The coefficient Fdt relative to the optimum disturbance value F/F component Uopfd is determined according to a predictive control algorithm on the assumption that the present exhaust gas temperature will continue until after the exhaust gas temperature predicting time Md. As a result, the stability of the process of controlling the element temperature T_{O2} at the target value R is effectively increased, and hence the stability of the output characteristics of the O_2 sensor 8 is also effectively increased.

According to the present embodiment, furthermore, the control input DUT is calculated as including the control input component depending on the target value R for the element temperature T_{O2} (the target value R from the present until after the target value predicting time Mr), i.e., the optimum target value F/F component Uopfr. When the target value R changes from a low temperature (600°C)

immediately after the engine 1 has started to operate to a normal high temperature (750°C through 800°C) in particular, the control input DUT is prevented from becoming temporarily large excessively, i.e., the element temperature T_{O2} is prevented from overshooting with respect to the target value R. The stability of the output characteristics of the O_2 sensor 8 is also effectively increased.

A second embodiment of the present invention will be described below with reference to FIG. 12. The second embodiment is partly different in arrangement or function from the first embodiment described above, and those structural or functional parts of the second embodiment which are identical to those of the first embodiment are denoted by identical reference characters, and will not be described in detail below.

According to the present embodiment, as shown in the block diagram of FIG. 12, the sensor temperature control means 18 of the control unit 16 shown in FIG. 1 comprises, as functional means, an exhaust temperature observer 19, an element temperature observer 20, a target value setting means 31, and a heater controller 32. The exhaust temperature observer 19 and the element temperature observer 20 are identical to those of the first embodiment. According to the present embodiment, however, the element temperature observer 20 corresponds to a heater temperature estimating means according to the present invention. In

the present embodiment, the target value setting means 31 and the heater controller 32 have their processing periods identical to the processing periods of the target value setting means 21 and the heater controller 22 according the first embodiment.

The target value setting means 31 serves to set a target value R' for the heater temperature Tht of the O_2 sensor 8. According to the inventors' knowledge, the heater temperature Tht is relatively highly correlated to the element temperature T_{O2} and tends to be higher than the element temperature T_{O2} by a constant temperature in a steady state. According to the present embodiment, the target value setting means 31 sets, as the target value R' for the heater temperature Tht, a value R + DR which is higher than the target value R for the element temperature T_{O2} that is set as described in the first embodiment (the target value R set by the processing sequence shown in FIG. 9), by a predetermined value DR (e.g., 100°C). As with the first embodiment, the target value R' that is set by the target value setting means 31 in each cycle time of its processing sequence is a target value after the target value predicting time Mr, and the target value R' in the period of the target value predicting time Mr is sequentially updated and stored.

The heater controller 32 sequentially generates the duty cycle DUT as a control input in order to keep the

heater temperature Tht at the target value R'. In the present embodiment, as with the first embodiment, the heater controller 32 calculates the duty cycle DUT according to an optimum predictive control algorithm.

More specifically, according to the present embodiment, attention is paid to the difference e' between the heater temperature Tht and a target value R' therefor, a change $\Delta e'$ per given time in the difference e' (corresponding to a rate of change of the difference e'), and a change ΔT_{o2} per given time in the element temperature T_{o2} (corresponding to a rate of change of the element temperature T_{o2}), and a model equation for an object to be controlled by the heater controller 32 is introduced using the above differences and changes as state quantities relative to the object to be controlled by the heater controller 32.

If the difference e' (hereinafter referred to as "heater temperature difference e'") is defined as $e'(n) = Tht(n) - R'(n)$, then the model equation is given as the following equation (25) based on the above equations (11-1), (11-2) according to the same idea as with the first embodiment:

$$X1(n+1) = \Phi' \cdot X1(n) + G' \cdot \Delta DUT(n) + Gd' \cdot \Delta Tgd(n) + Gr' \cdot R1(n+1)$$

$$\cdots (25)$$

where $X1(n) = (e'(n), \Delta e'(n), \Delta T_{o2}(n))^T$,

$\qquad R1(n+1) = (\Delta R'(n+1), \Delta R'(n))^T$,

$\qquad G' = (0, Dx \cdot dtc, 0)^T$,

$$Gd' = (0,0,Ax \cdot dtc)^T,$$

$$\Phi' = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1-Cx \cdot dtc & Cx \cdot dtc \\ 0 & Bx \cdot dtc & 1-Ax \cdot dtc-Bx \cdot dtc \end{bmatrix}$$

$$Gr' = \begin{bmatrix} 0 & 0 \\ -1 & 1-Cx \cdot dtc \\ 0 & Bx \cdot dtc \end{bmatrix}$$

In the present embodiment, the control input DT to be determined by the heater controller 32 is given by the equation (27) shown below as having integrated ΔDUT which minimizes an evaluating function J1 according to the following equation (26):

$$J1 = \sum_{n=-M+1}^{\infty} [X1^T(n) \cdot Q0 \cdot X1(n) + \Delta DUT^T(n) \cdot H0 \cdot \Delta DUT(n)] \quad \cdots (26)$$

where M = max(M, Md)

$$DUT(n) = Fs1 + \sum_{j=1}^{n} e'(j) + Fe1 \cdot e'(n) + Fx1 \cdot T_{02}(n)$$
$$+ \sum_{i=1}^{Mr}[Fr'(i) \cdot R'(n+1)] + Fdt' \cdot Tgd(n) \quad \cdots (27)$$

The coefficients Fs1, Fe1, Fx1 in the first through third terms, the coefficient Fr'(i) (i = 0, 1, $\cdots$, Mr) in the fourth term, and the coefficient Fdt' in the fifth term on the right side of the equation (27) are coefficients given respectively by the following equations (28-1) through (28-3):

$$F1 \equiv (Fs1, Fe1, Fx1)$$
$$= - [H0 + G'^T \cdot P' \cdot G']^{-1} \cdot G'^T \cdot P' \cdot \Phi'$$

$\cdots (28-1)$

$$Fr'(i) = \begin{cases} Fr12(1) & :i = 0 \\ Fr11(i) + Fr12(i+1) & :i = 1,2,\cdots,Mr-1 \\ Fr11(Mr) & :i = Mr \end{cases}$$

$$\cdots (28-2)$$

$$Fdt' = \sum_{i=0}^{Md} \{-[H0 + G'^{T} \cdot P' \cdot G']^{-1} \cdot G'^{T} \cdot (\zeta'^{T})^{i} \cdot P' \cdot Gd'\} \quad \cdots (28-3)$$

where $P' = Q0 + \Phi'^{T} \cdot P' \cdot \Phi'$

$$- \Phi' \cdot P' \cdot G' \cdot [H0 + G'^{T} \cdot P' \cdot G']^{-1} \cdot G'^{T} \cdot P' \cdot \Phi'$$

$$\zeta' = \Phi' + G' \cdot F1$$

$$(Fr11(i), Fr12(i))$$

$$= - [H0 + G'^{T} \cdot P' \cdot G']^{-1} \cdot G'^{T} \cdot (\zeta'^{T})^{i-1} \cdot P' \cdot Gr'$$

$$(i = 1, 2, \cdots, Mr)$$

In the present embodiment, the weighted matrixes Q0, H0 with respect to the evaluating function J1, the target value predicting time Mr, and the exhaust gas temperature predicting time Md are identical to those in the first embodiment. However, they may be set to values different from those in the first embodiment. The coefficients Fs1, Fe1, Fx1, Fr'(i), Fdt' in the equation (27) may not necessarily be of the values according to the defining equations (28-1) through (28-3), but may be of values adjusted by way of simulation or experimentation. Furthermore, the coefficients Fs1, Fe1, Fx1, Fr'(i), Fdt' may be changed depending on the element temperature, the heater temperature, etc. In the present embodiment, as with the first embodiment, the exhaust gas temperature Tgd is maintained at the present value in the future until after Md steps. However, if Tgd at each time in the future can be detected or esti-

mated, then the control input DUT may be determined using those values (in this case, Fdt' is a vector).

The above equation (27) is a formula for sequentially calculating a control input DUT(n) (duty cycle) with which the heater controller 32 controls the heater 13 in the present embodiment. Specifically, the heater controller 32 sequentially calculates the control input DUT(n) in each cycle time (period) of the control processing of the heater controller 32 according to the equation (27), and applies a pulse voltage having the duty cycle DUT(n) to a heater energizing circuit, not shown, thereby adjusting the electric power supplied to the heater 13. The terms on the right side of the equation (27) have the same meanings as those in the first embodiment. Specifically, the first through third terms (the term including $\sum e'(j)$ through the term including $T_{o2}(n)$) on the right side represent a control input component (a feedback component based on an optimum control algorithm) depending on the heater temperature difference e' and the element temperature T_{o2}. The fourth term (the term of $\sum Fr'(i) \cdot R'(n+i)$) on the right side of the equation (27) and the fifth term (the term including Tgd(n)) on the right side thereof represent a control input component (a feed-forward component based on a predictive control algorithm) depending on the exhaust gas temperature Tgd.

As the element temperature T_{o2} and the exhaust gas temperature Tgd that are required to determine the control input DUT(n) according to the equation (27), there are employed, respectively, the latest value of the estimated value of the element temperature T_{o2} determined by the element temperature observer 20 and the latest value of the estimated value of the exhaust gas temperature Tgd determined by the exhaust temperature observer 19.

The heater temperature difference e' required for the calculation according to the equation (27) is calculated from the latest value of the estimated value of the heater temperature Tht determined by the element temperature observer 20 and the target value R' that has been set in a cycle time before the target value predicting time Mr by the target value setting means 31.

The other processing details than those described above are identical to those according to the first embodiment. In the present embodiment, the electric power supplied to the heater 13 of the O_2 sensor 8 is controlled in order to maintain the heater temperature Tht of the O_2 sensor 8 at the target value R'. In this case, except immediately after the engine 1 starts to operate or when the atmospheric temperature T_A is considerably low, the target value R' is usually set to a temperature (900°C) which is higher than a preferred target temperature of 800°C for the active element 10 by a predetermined value DR (100°C in the

present embodiment). As a result, the temperature T_{O2} of the active element 10 of the O_2 sensor 8 is indirectly controlled substantially at the temperature of 800°C. Therefore, as with the first embodiment, the output characteristics of the O_2 sensor 8 can stably be kept as characteristics suitable for controlling the air-fuel ratio of the engine 1 (for controlling the air-fuel ratio to keep a good purifying capability of the catalytic converter 4), and hence the air-fuel ratio is controlled well to reliably keep a good purifying capability of the catalytic converter 4. During a predetermined period of time immediately after the engine 1 has started to operate, the target temperature R' for the heater 13 is set to a temperature (700°C) which is higher than a low temperature (600°C) as the target temperature R for the active element 10 than the predetermined value DR, for thereby preventing the active element 10 from being damaged by stresses due to abrupt heating. If the atmospheric temperature T_A is low ($T_A < 0$°C), then inasmuch as the target value R for the active element 10 is set to a value in the range of 750°C $\leq$ R < 800°C, the target value R' for the heater 13 is set to a value in the range of 850°C $\leq$ R' < 900°C to prevent the heater 13 from being overheated.

According to the present embodiment, since the algorithm of the element temperature observer 20 is the same as the algorithm according to the first embodiment,

the accuracy of the estimated values of the element temperature T_{O2} and the heater temperature Tht is sufficiently maintained. The duty cycle DUT as a control input to the heater 13 includes the control input component (the first term (the term including $\sum e'(j)$) and the second term (the term including $e'(n)$) of the equation (27)) depending on the estimated value of the heater temperature Tht, and the control input component (the third term of the equation (27)) depending on the estimated value of the element temperature T_{O2}. In addition, according to the present embodiment, a predictive control algorithm is also applied, and the duty cycle DUT includes the control input component (a feed-forward component of the fifth term on the right side of the equation (27)) depending on the exhaust gas temperature Tgd, and the control input component (a feed-forward component of the fourth term on the right side of the equation (27)) depending on the target value R'. As a result, the heater temperature Tht can reliably be controlled stably at the desired target value R', and the element temperature T_{O2} can be controlled stably at a desired temperature.

In the first and second embodiments described above, the exhaust gas temperature Tgd is estimated. However, an exhaust gas sensor may be disposed in the vicinity of the O_2 sensor 8, and the exhaust gas temperature Tgd may be detected by the exhaust gas sensor. In this case, the

element temperature Tht is estimated using the detected value (latest value) of the exhaust gas temperature sensor as the value of the exhaust gas temperature Tgd in the equation (10-1). The duty cycle DUT may be calculated using the detected value (latest value) of the exhaust gas temperature sensor as the value of the exhaust gas temperature Tgd in the equation (24) or (27).

In the first and second embodiments, both the element temperature T_{O2} and the heater temperature Tht are estimated. However, either one of them may be detected directly by a temperature sensor. If the element temperature T_{O2} is detected, then the heater temperature Tht may be estimated using the detected value (latest value) of the element temperature T_{O2} as the value of the element temperature T_{O2} in the equation (10-2), and the duty cycle DUT may be calculated using the detected value (latest value) of the element temperature T_{O2} as the value of the element temperature T_{O2} in the equation (27). If the heater temperature Tht is detected, then the element temperature T_{O2} may be estimated using the detected value (latest value) of the heater temperature Tht as the value of the heater temperature Tht in the equation (10-1), and the duty cycle DUT may be calculated using the detected value (latest value) of the heater temperature Tht as the value of the heater temperature Tht in the equation (24).

In the first and second embodiments, the element temperature T_{O2} of the O_2 sensor 8 or the heater temperature Tht is controlled at the target value R or R' according to the optimum predictive control algorithm. However, the control input DUT may be generated according to another control algorithm (e.g., an ordinary PI or PID control process).

Alternatively, the control input DUT may be determined according to an ordinary optimum control algorithm which includes no predictive control algorithm. In this case, the control input DUT may sequentially be calculated according to an equation which is produced by removing the fourth term (the term including R(n+i)) and the fifth term (the term including Tgd(n)) from the equation (24) or by removing the fourth term (the term including R'(n+i)) and the fifth term (the term including Tgd(n)) from the equation (27). According to this modification, the heater controller for determining the control input DUT is an optimum servocontroller for determining the control input DUT in order to minimize the value of the evaluating function J0 or J1 where M = 0 in the equation (17) or (26).

In each of the embodiments described above, the element temperature T_{O2} of the O_2 sensor 8 is controlled. However, the present invention is also applicable to an exhaust gas sensor other than the O_2 sensor 8 (e.g., the wide-range air-fuel ratio sensor 9 or a humidity sensor for

generating an output signal representative of the water content of the exhaust gas). In this case, an algorithm for estimating the element temperature or the heater controller may be the same as the algorithm in the first embodiment and the second embodiment.

The internal combustion engine to which the present invention is applicable may be an ordinary port-injected internal combustion engine, a spark-ignition internal combustion engine with direct fuel injection into cylinders, a diesel engine, an internal combustion engine for use as an outboard engine on a boat, etc.

Industrial applicability:

As described above, the present invention is useful as a technology for appropriately controlling the temperature of an exhaust gas sensor disposed in the exhaust system of an internal combustion engine mounted on an automobile, a hybrid vehicle, an outboard engine assembly, or the like, at a desirable temperature for stabilizing the output characteristics of the exhaust gas sensor.